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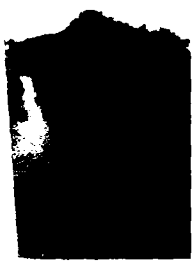

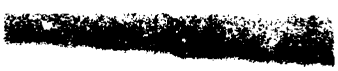

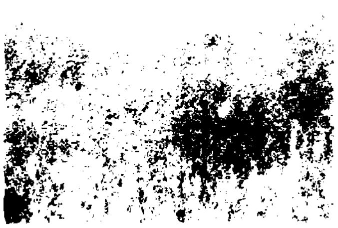

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TECHNICAL REPORT EL-89-2

ENGINEERING AND ECONOMIC ANALYSIS OF CONTAINMENT AREA/WETLANDS DISPOSAL OPTIONS IN NEW YORK HARBOR

by

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Investigations were conducted to evaluate the engineering feasibility of constructing dredged material disposal sites at four locations within the New York Harbor area. The four sites identified by the New York District for evaluation were Bowery Bay, New York; Flushing Bay, New York; Newark Bay, New Jersey; and Raritan Bay, New Jersey. Each of these locations was evaluated for use with three disposal options: (a) disposal of uncontaminated sediments in a containment area; (b) disposal of contaminated sediments in a containment area; and (c) disposal of uncontaminated sediments to stabilize/create wetland habitats.

Geotechnical analyses were conducted to evaluate the feasibility and cost of dredged material retaining dike construction. Retaining dike construction was found to be technically feasible, and a recommended dike design was presented for each site. Storage capacity evaluations were conducted for each disposal option to determine the ultimate quantity of

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Containment area	Dredged material disposal	Marsh development
Construction	Dredging	Wetlands
Construction costs	Disposal site	
Dredged material	Environmental engineering	

19. ABSTRACT (Continued).

material to be placed at each site. Total costs associated with each disposal option were determined including costs for marsh plantings.

SUMMARY

This report presents the results of investigations conducted by the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District, New York. Preliminary retaining dike designs and dike construction costs were determined by the WES Geotechnical Laboratory (GL). Storage capacity evaluations for containment area and wetland stabilization were performed by the WES Environmental Laboratory (EL); this report was prepared by EL.

The objectives of this study were to determine the feasibility of constructing dredged material disposal sites at four selected locations in the New York Harbor area and to evaluate three disposal options at each site. The disposal options considered were: (a) disposal of uncontaminated sediments in a containment area; (b) disposal of contaminated sediments in a containment area; and (c) disposal of uncontaminated sediments to stabilize/create a wetland habitat. The four sites under consideration were Bowery Bay, New York; Flushing Bay, New York; Newark Bay, New Jersey; and Raritan Bay, New Jersey.

Geotechnical analysis and evaluations of the four potential disposal sites were performed by GL. It was determined, based upon data provided by the New York District, that the required retaining dikes could be built at each of the four sites. Recommended preliminary dike designs were developed for each of the disposal sites. Costs for dike construction were determined and were based upon the most recent unit costs available for various construction materials; costs are reported in 1985 dollars unless otherwise noted. The detailed GL reports are attached as Appendixes A through D while an abbreviated description is given in Part II.

Storage capacity evaluations were performed for each of the three disposal options at each of the disposal sites. Quantities and physical properties of sediment to be placed in each of the disposal sites were provided by the New York District. Utilizing a finite strain consolidation/desiccation computer model, projections were made of the ultimate quantity of material which could be placed in each disposal site, and the expected service life of the site was determined. The analyses of containment areas for both contaminated and uncontaminated sediments are contained in Part III. The wetlands analysis is discussed in Part IV.

The costs associated with each disposal option were compared in Part V. The costs included only dike construction and marsh planting costs. Both

total costs and unit costs were compared for each disposal option. The following summary tabulates the results of this investigation. Costs reported in this tabulation are in 1988 dollars.

Disposal Site	Ultimate Volume of Sediment Contained yd^3	Service Life years	Total Cost* $	Cost/Vol of Contained Dredged Material, $/yd^3$
	Containment Area (Uncontaminated)			
Bowery Bay	1.99 M	1.75	3.3 M	1.66
Flushing Bay	1.39 M	1.25	8.9 M	6.40
Newark Bay	4.83 M	3.5	19.9 M	4.12
Raritan Bay	11.40 M	20.0	13.2 M	1.16
	Containment Area (Consolidated)			
Bowery Bay	1.69 M-3.55 M	9-20	3.3 M	0.93-1.95
Flushing Bay	1.18 M-2.87 M	6-16	8.9 M	3.10-7.54
Newark Bay	4.06 M-6.76 M	23-40	19.9 M	2.94-4.90
Raritan Bay**	5.92 M	35	13.2 M	2.23
	Wetland Creation			
Bowery Bay	2.30 M	6	3.7 M	1.61
Flushing Bay	1.73 M	6	9.1 M	5.26
Raritan Bay	5.97 M	13	15.0 M	2.51

* Costs in 1988 dollars.
** No surface drying.
† Five disposal operations in 6 years.
†† Four disposal operations in 6 years.

PREFACE

This technical report was prepared by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). Funding for this investigation was authorized by IAO 85-4 dated 15 January 1985. Investigations reported in Part II and Appendixes A-D of this report were conducted by the Geotechnical Laboratory (GL), WES, and were funded by IAO 84-72 dated 25 June 1984.

The report was written by Dr. Marian E. Poindexter, under the general supervision of Dr. Michael R. Palermo, Chief, Water Resources Engineering Group (WREG), EL; Dr. Raymond L. Montgomery, Chief, Environmental Engineering Division, EL; and Dr. John Harrison, Chief, EL. During report publication, Dr. John J. Ingram was Chief, WREG. Acknowledgment is made to Dr. Mary C. Landin for her contributions to the section on wetlands stabilization. This report was edited by Mr. Bobby Odom, Information Technology Laboratory, under the Intergovernmental Personnel Act.

Reports included as Appendixes A-D were written by Dr. Myron L. Hayden, under the general supervision of Mr. G. B. Mitchell, Chief, Engineering Group, Soil Mechanics Division (SMD), GL; Mr. C. L. McAnear, Chief, SMD; Dr. Paul F. Hadala, Assistant Chief, GL; and Dr. William F. Marcuson III, Chief, GL.

COL Dwayne G. Lee, EN, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

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CONTENTS

LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
pounds (force) per square foot	47.88026	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square yards	0.8361274	square metres
tons (force) per square foot	95.76052	kilopascals
yards	0.9144	metres

ENGINEERING AND ECONOMIC ANALYSIS OF CONTAINMENT AREA/WETLANDS DISPOSAL OPTIONS IN NEW YORK HARBOR

PART I: INTRODUCTION

Background

1. Many studies have been conducted to identify and evaluate potential disposal alternatives for sediments dredged from the New York Harbor area. The work has been conducted under the sponsorship of the US Army Engineer District, New York (New York District), as a part of the Dredged Material Disposal Management Plan for the Port of New York and New Jersey. Initial identification and screening of potential disposal sites were accomplished by the New York District in conjunction with the Steering Committee for the Dredged Material Disposal Management Plan for the Port of New York and New Jersey; some technical assistance was provided by the US Army Engineer Waterways Experiment Station (WES). One disposal alternative of particular interest, which is addressed in this report, is that of confined disposal involving creation of either a confined upland or wetland site.

2. Previous assistance provided by WES as a Dredging Operations Technical Support request for assistance had resulted in preliminary identification of nine potential sites for containment/wetlands creation. These sites were ranked according to their feasibility of construction, comparative cost, disposal capacity, and potential for marsh creation. Further evaluation by the New York District resulted in elimination of five of the nine sites from consideration. The four sites which remained under consideration were Raritan Bay, Bowery Bay, Flushing Bay (North), and Newark Bay. This report will present a more detailed analysis of these four sites.

Scope

3. The purpose of this investigation was to evaluate the feasibility of constructing containment facilities and wetland stabilized areas at three of the four dredged material disposal sites. These included Raritan Bay, Bowery Bay, and Flushing Bay (North). The Newark Bay site was considered for a small

containment island only. Both the engineering and economic feasibility were evaluated for the various alternatives. This work included: (a) analysis of the constructibility of each type of facility (containment area and wetland) at each site; (b) summarization of all feasible site construction scenarios; (c) identification of potential engineering problems associated with each scenario; (d) estimation of construction costs for each scenario (in 1985 dollars unless noted otherwise); and (e) determination of estimated containment area/wetland storage capacity for dredged material. This work was divided into two packages with the WES Geotechnical Laboratory (GL) being responsible for cost estimates and dike design and construction consideration/recommendations; the Environmental Laboratory was responsible for wetland stabilization recommendations, site capacity projections for each scenario, development of recommendations and report preparation. This report did not consider or evaluate the control measures necessary to handle contaminated sediments; neither technical descriptions nor costs were addressed. Control measures for contaminated sediments should be considered in future studies which must be conducted before implementation of disposal of contaminated dredged material.

PART II: DIKE DESIGN AND CONSTRUCTION

4. As part of the engineering and economic feasibility study for development of dredged material disposal sites in the New York Harbor area, geotechnical analyses and evaluations of the four sites were performed. These geotechnical analyses were performed by the GL, Soil Mechanics Division, and are based upon limited subsurface data provided to WES by the New York District.

5. Probable subsurface conditions and information on recommended dike design and construction scenarios for each of the four dredged material disposal sites are described in the following paragraphs. Individual geotechnical reports for the four sites are included as appendixes to this report (Appendixes A-D).

Bowery Bay

Site conditions

6. The Bowery Bay dredged material disposal site is adjacent to La Guardia Airport (as shown in Figure A2). The New York District in conjunction with the Steering Committee proposed the boundaries of this site. The entire site initially encompassed approximately 75 acres.* As a result of the GL economic analysis, the portion of the site identified as Area B was eliminated from consideration. The remaining portion, Area A, encompasses approximately 67 acres, including the area required for construction of 1,700 ft of dike along the north and northwest sides of the disposal site.

7. The bottom of the disposal site, or conversely the top of the foundation soils, has an average elevation (el) of approximately -7 ft mean low water (mlw). The land which presently exists adjacent to the disposal site has an elevation of +10 ft mlw; small perimeter dikes have been constructed to el +15 mlw on the east, el +12 ft mlw on the south, and el +14 mlw on the west.

Foundation soils

8. The foundation soils at the Bowery Bay disposal site (see Figures A3 and A4) typically consist of 6 ft of very soft organic silt underlain

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 7.

by 14 ft of soft sandy silt. Immediately below the sandy silt is a 16-ft-thick layer of medium dense silty sand. The silty sand is underlain, respectively, by a thin layer of silt and a dense silty, gravelly sand which extends to an undetermined depth.

9. A simplified foundation soil profile was assumed for dike design considerations as shown in Figure A5. Figure A5 also indicates values used for several soil parameters which were needed for analysis of various dike design scenarios. Values of soil cohesion c and angle of internal friction ϕ were obtained from correlations with standard penetration test (SPT) data. The values shown in Figure A5 for the soil parameters are consistent with the limited available foundation data.

Dike design considerations

10. The design of stable dikes requires analysis of the proposed dike for several possible modes of failure. These include overtopping/erosion of the dikes, bearing capacity failure, rotational or translational slope failure, and excessive settlement. The latter three possible modes of failure relate particularly to the soft foundation soils while the former mode could result from storm surges, high tides, and wakes caused by large ships. Each of these modes of failure should be considered in any future design of retaining dikes at this site.

11. The maximum height of the dike constructed at this disposal site will depend upon both foundation soil-bearing capacities and the type of disposal site created. The ultimate bearing capacities of the two soft foundation soils were determined to be approximately 275 psf for the organic silt and 800 psf for the sandy silt. As a result of these low bearing capacities, failure of both soft foundation soils will probably occur by the time dike construction reaches el 0 ft mlw. A bearing capacity failure in soils of the consistency encountered at this site generally results in the formation of a mud wave which is caused by lateral displacement of the soft foundation soils. Construction procedures should probably be implemented to eliminate/reduce formation of a mud wave or to remove some of the displaced soils in order to reduce the potential impact on the surrounding marine environment.

12. Construction of a confined disposal site should provide dikes of sufficient height to reduce the likelihood and detrimental effects (erosion, etc.) of overtopping of the dikes resulting from water levels associated with the design storm event. A minimum of 2 ft of freeboard above the design storm

surge elevation should be provided on all containment area dikes. This is particularly important if contaminated sediments are to be confined in the disposal site since no mixing of the contaminated materials with the environment outside the containment area should be allowed. Storm-surge return intervals and corresponding water level elevations for Bowery Bay are shown in Table 1.

13. In the creation of wetlands, retaining dikes must be considered to be permanent structures when they are used to retain fine-grained material such as the case at Bowery Bay. The need for 2 ft of freeboard is not as critical since uncontaminated sediments would be used in wetland creation; therefore, the necessity for completely isolating the sediments from the surrounding environment would be eliminated. Any damage from occasional dike overtopping could be repaired for less than the cost of constructing dikes to the initial height necessary to reduce the likelihood of overtopping.

Recommended dike design

14. The type of dike recommended for the Bowery Bay disposal site is a fabric reinforced dike. Use of a reinforcing fabric having the ability to withstand high tensile stresses and to maximize frictional forces at the soil-fabric interface will allow use of side slopes as steep as 1V:4H, instead of the maximum slope of 1V:6H which would be necessary for nonreinforced dikes. The dikes with steeper slopes will require less construction material, and thus the cost will be significantly reduced.

15. Because of the low bearing capacity of the soft foundation soils and the height of dike required at Bowery Bay, it is anticipated that both the soft organic silt and the sandy silt below the dike will fail from the increased load. In the worst case, only 1 ft of sandy silt would remain below the dike, and all other soft foundation material would move laterally to form a mud wave. For this scenario, which is shown in Figure A6, a fill volume of approximately 243 yd^3/lin ft of dike would be required to construct the dike, to a crest elevation of +10 ft mlw. Slope protection must be used on the exterior of all constructed dikes. Details of the recommended construction procedure are given in Appendix A.

16. The only dike designs provided in the GL report had dike crest elevations of +10 mlw (see Appendix A). It is assumed, although not stated in the GL report, that this dike crest elevation is a compromise height based upon foundation soil-bearing capacity and other factors in addition to storm

surge elevations since a crest elevation of +10 mlw does not allow for the recommended 2 ft of freeboard above even a 1-year return interval storm surge. The dike crest elevation and the resulting cost estimate could be modified through further geotechnical analyses to increase or decrease the dike height as deemed appropriate for various containment/wetland creation scenarios.

Flushing Bay

Site conditions

17. The proposed dredged material disposal site in Flushing Bay is located in the southwest corner of the bay adjacent to La Guardia Airport; the proposed boundaries of this site were identified by the New York District in conjunction with the Steering Committee. The site encompasses approximately 59 acres including the area required for construction of approximately 3,800 ft of dikes along all but the southern side of the disposal site. The disposal site location as well as the location of soil profile sections within the site is shown in Figure B2.

18. The bottom of the disposal site (or the top of the foundation soils) has an average elevation of approximately -5 ft mlw. The land adjacent to the disposal site is at el +10 ft mlw with a small perimeter dike which extends up to el +15 ft mlw.

Foundation soils

19. The foundation soils at the Flushing Bay disposal site consist of a soft silt stratum with an average thickness of 64 ft. This soft silt is underlain by a dense to very dense sand which extends to an undetermined depth but is at least 30 ft thick. Soil profile sections A-A and B-B are shown in Figures B3 and B4, respectively.

20. For dike design considerations, a simplified foundation soil profile which is believed to be representative of the average soil profile beneath the dikes was assumed as shown in Figure B5. This figure also indicates values used for several soil parameters which were needed for analysis of various dike design scenarios. Values of soil cohesion c and angle of internal friction ϕ were obtained from correlations with SPT data.

Dike design considerations

21. The design of stable dikes requires analysis of the proposed dike for several possible modes of failure. These include overtopping/erosion of

the dikes, bearing capacity failure, rotational or translational slope failure, and excessive settlement. The latter three possible modes of failure relate particularly to the soft foundation soils while the former mode could result from storm surges, high tides, and wakes caused by large ships. Each of these modes of failure should be considered in any final design of retaining dikes at this site.

22. The maximum height of the dike constructed at this disposal site will depend upon both foundation soil-bearing capacities and the type of disposal site created. The ultimate bearing capacity of the soft organic silt was determined to be approximately 400 psf. As a result of the low bearing capacity of this material, dikes could only be constructed to el +0.5 ft mlw before failure of the foundation soil would occur. A bearing capacity failure in a soil of the consistency encountered at this site would result in lateral displacement of the foundation soil and formation of a mud wave. Based upon data obtained during relocation of an adjacent runway at La Guardia Airport, a reasonable, but conservative, assumption would be that 26 ft of the soft organic silt would be displaced as a result of dike construction. Because of the large quantities of material which are expected to be displaced, it is recommended that the outside toe of the dikes be set back a minimum of 200 ft from the nearest ship channel and/or from any bridge or runway piling. This would minimize intrusion of the displaced material into the ship channel and development of negative skin friction on pilings.

23. Construction of a confined disposal site should provide dikes of sufficient height to reduce the possibility of overtopping and subsequent possible erosion of the dikes. A minimum of 2 ft of freeboard above the design storm surge elevation should be provided on all containment area dikes. This is particularly important if contaminated sediments are to be confined in the disposal site since no mixing of the contaminated materials with the environment outside the containment area should be allowed. Storm-surge return intervals and corresponding water level elevations for Flushing Bay are shown in Table 2.

24. In the creation of wetlands, although retaining dikes are considered to be permanent structures when they are used to retain fine-grained material, the need for 2 ft of freeboard is not as critical since uncontaminated sediments would be used in wetland creation. Therefore the necessity for completely isolating the sediments from the surrounding environment would

be eliminated. Any damage from occasional dike overtopping could be repaired for less than the cost of constructing the dikes to an initial height which would reduce the likelihood of overtopping.

Recommended dike design

25. The dike design recommended for the Flushing Bay disposal site is a fabric reinforced dike. Use of a reinforcing fabric with the ability to withstand high tensile stresses and to maximize frictional forces at the soil-fabric interface will allow use of side slopes as steep as 1V:4H instead of the flatter slopes (1V:6H) required for nonreinforced dikes. The dikes with steeper slopes will require less construction material and thus the cost will be significantly reduced.

26. Because of the low bearing capacity of the soft foundation soil in conjunction with the height of the dike required at Flushing Bay, it is anticipated that the soft organic silt below the dike will fail. The failure and subsequent lateral movement of the silt is expected to extend approximately 26 ft into the silt layer. For this scenario, which is shown in Figure B7, a fill volume of 217 yd^3/lin ft of dike would be required to construct the dike to a crest elevation of +10 ft mlw. Slope protection must be used on the exterior of all constructed dikes. Details of the recommended construction procedure are given in Appendix B.

27. The only dike designs provided in the GL report had dike crest elevations of +10 ft mlw (see Appendix B). It is assumed, although not stated in the GL report, that this dike crest elevation is a compromise height based upon foundation soil-bearing capacity and other factors in addition to storm surge elevations since a crest elevation of +10 ft mlw does not allow for the recommended 2 ft of freeboard above even a 1-year return interval storm surge. The dike crest elevation and the resulting cost estimate could be modified through further geotechnical analyses to increase or decrease the dike height as deemed appropriate for various containment/wetland creation scenarios.

Newark Bay

Site conditions

28. The proposed dredged material disposal site at Newark Bay is located south of Port Newark on the west side of Newark Bay. The disposal site is bound on all sides by ship channels with the Port Newark Channel to

the north, Newark Bay Channel (middle reach) to the east, Elizabeth Channel to the south, and the Port Newark Pierhead Channel to the west. The proposed boundaries of this site were identified by the New York District in conjunction with the Steering Committee. The site encompasses approximately 165 acres including the area required for construction of all retaining dikes. The disposal site location, as well as the location of soil profile sections used for this site, is shown in Figure C2.

29. The bottom of the disposal site (or the top of the foundation soils) has an average elevation of -5 ft mlw. The surrounding port facilities have been constructed to at least el +10 ft mlw.

Foundation soils

30. Because there were no soil borings within the proposed disposal site, an assumed soil profile was developed by using logs of borings made close to the site. Borings utilized were from Port Newark and were located about 800 ft north of the proposed disposal site. The foundation soils at the Newark Bay disposal site are assumed to consist of approximately 23 ft of soft organic silt underlain by a firm silty clay interbedded with layers of medium-dense sand and silty sand. The silty clay and sands have an average thickness of 16 ft. This layer is underlain respectively by a 14-ft-thick layer of firm gravelly silt and silty clay and a 20-ft layer of firm silty clay. Below the firm silty clay is rock which begins at about el -80 ft mlw and extends indefinitely. Soil profile sections A-A and B-B are shown in Figure C3 and C4, respectively.

31. For the dike design considerations, a simplified foundation soil profile which is believed to be representative of the average soil profile beneath the dikes was assumed as shown in Figure C5. This figure also indicates values used for several soil parameters which were needed for analysis of various dike design scenarios. Values of soil cohesion c and angle of internal friction ϕ were obtained from correlations with SPT data.

Dike design considerations

32. The design of stable dikes requires analysis of the proposed dike for several possible modes of failure. These include overtopping/erosion of the dikes, bearing capacity failure, rotational or translational slope failure, and excessive settlement. The latter three possible modes of failure relate particularly to the soft foundation soils while the former mode could result from storm surges, high tides, and wakes caused by large ships. Each

of these modes of failure should be considered in any final design of retaining dikes at this site.

33. The maximum height of the dike constructed at this disposal site will depend upon both foundation soil-bearing capacities and the type of disposal site created. The ultimate bearing capacity of the soft organic silt was determined to be approximately 400 psf while the underlying firm silty clay has an ultimate bearing capacity of about 5,000 psf. As a result of the low bearing capacity of the soft organic silt, dikes could be constructed only to el 0 ft mlw before failure of this material would occur. A bearing capacity failure in a soft soil of the consistency encountered at this site would result in lateral displacement of the foundation soil and formation of a mud wave. The underlying firm silty clay should provide adequate bearing capacity for the dikes needed at Newark Bay although they will undergo some consolidation.

34. Construction of a confined disposal site should provide dikes of sufficient height to prevent overtopping and subsequent possible erosion of the dikes. A minimum of 2 ft of freeboard above the design storm surge elevation should be provided on all contaminant area dikes. This is particularly important if contaminated sediments are to be confined in the disposal site, since no mixing of the contaminated materials with the environment outside the containment area should be allowed. Storm-surge return intervals and corresponding water level elevations for Newark Bay are shown in Table 3.

35. In the creation of wetlands, retaining dikes must be considered to be permanent structures when they are used to retain fine-grained material as in the case at Newark Bay. The need for 2 ft of freeboard is not as critical since uncontaminated sediments would be used in wetland creation; therefore, the necessity for completely isolating the sediments from the surrounding environment would be eliminated. Any damage from occasional dike overtopping could be repaired for less than the cost of constructing the dikes to an initial height which would eliminate overtopping.

Recommended dike design

36. The type of dike recommended for the Newark Bay disposal site is a fabric reinforced dike. Use of a reinforcing fabric with the ability to withstand high tensile stresses and to maximize frictional forces at the soil-fabric interface will allow use of side slopes as steep as 1V:4H instead of the flatter slopes required for nonreinforced dikes. The dikes with steeper

slopes will require less construction material, and thus the cost will be significantly reduced.

37. Because of the low bearing capacity of the soft foundation soil in conjunction with the height of the dike required at Newark Bay, it is anticipated that the soft organic silt will fail below the dike. In the worst case, only 1 ft of the soft organic silt would remain below the dike while the remainder of this material would move laterally to form a mud wave. For this scenario, which is shown in Figure C7, a fill volume of 273 yd^3/lin ft of dike would be required to construct the dike to a crest elevation of +12 ft mlw. Slope protection must be used on the exterior of all constructed dikes. Details of the recommended construction procedure are given in Appendix C.

38. All dike designs provided in the GL report for Newark Bay were ones with dike crest elevations of +12 ft mlw (see Appendix C). This provides for 2 ft of freeboard above the maximum surge associated with a storm of a 30-year return interval. The dike crest elevation and the resulting cost estimate could be modified through additional geotechnical analyses to increase or decrease the dike height as deemed appropriate for various containment/wetland creation scenarios.

Raritan Bay

Site conditions

39. The proposed dredged material disposal site at Raritan Bay is located adjacent to South Amboy, NJ, in the northwestern portion of Raritan Bay. The site is bordered on the north by the Raritan River and Arthur Kill ship channel. The location of the proposed disposal site is shown in Figure D1. Also shown in this figure are the three subdivisions of the area referred to as Areas A, B, and C. Area A encompasses approximately 278 acres while Areas B and C encompass 72 acres and 40 acres, respectively; thus the entire Raritan Bay disposal site encompasses about 390 acres. Because several structures including a sewage disposal facility and a ship loading dock presently exist in Area C and would require relocation, the New York District requested that only Areas A and B be considered for dredged material disposal.

40. The bottom of the disposal site (or the top of the foundation soil) has an average elevation of approximately -1 ft mlw. Area A is bordered on

the western side by an area designated as wetlands while Area B is adjacent to an area currently under development.

Foundation soils

41. As shown in Figure D2, the foundation soils at the Raritan Bay disposal site typically consist of about 35 ft of very soft organic silts. Interbedded within these soft silts are lenses of fine sand. A medium dense fine sand underlies the soft silt and extends to an undetermined depth.

42. For dike design considerations, a simplified foundation soil profile was assumed as shown in Figure D3. This figure also indicates values used for several soil parameters which were needed for analysis of various dike design scenarios. Values of soil cohesion c and angle of internal friction ϕ were obtained from correlations with penetration test data. The values shown in Figure D2 for the soil parameters are believed to be representative of the foundation soils at the site.

Dike design considerations

43. The design of stable dikes requires analysis of the proposed dike for several possible modes of failure. These include overtopping/erosion of the dikes, bearing capacity failure, rotational or translational slope failure, and excessive settlement. The latter three possible modes of failure relate particularly to the soft foundation soils while the former mode could result from storm surges, high tides, and wakes caused by large ships. Each of these modes of failure should be considered in any final design of retaining dikes at this site.

44. The maximum height of the dike constructed at this disposal site will depend upon both foundation soil-bearing capacity and the type of disposal site created. The ultimate bearing capacity of the soft organic silt was determined to be approximately 400 psf. As a result of the low bearing capacity of this material, dikes could be constructed only to el +2 ft mlw before failure of this material would occur. A bearing capacity failure in a soft soil of the consistency encountered at this site would result in lateral displacement of the foundation soil and formation of a mud wave. The underlying medium dense fine sand should provide adequate bearing capacity for the dikes needed at Raritan Bay if bearing is not established in the lower portion of the soft silt.

45. Construction of a confined disposal site should provide dikes of sufficient height to reduce overtopping and subsequent possible erosion of the

dikes. A minimum of 2 ft of freeboard above the design storm-surge elevation should be provided on all containment area dikes. This is particularly important if contaminated sediments are to be confined in the disposal sites since no mixing of the contaminated materials with the environment outside the containment area should be allowed. Storm-surge return intervals and corresponding water level elevations for Raritan Bay are shown in Table 4.

46. In the creation of wetlands, retaining dikes are considered to be permanent structures when they are used to retain fine-grained material. The need for 2 ft of freeboard is not as critical since uncontaminated sediments would be used in wetland creation; therefore, the necessity for completely isolating the sediments from the surrounding environment would be eliminated. Any damage from occasional dike overtopping could be repaired for less than the cost of constructing the dikes to an initial height which would eliminate overtopping.

Recommended dike design

47. The type of dike recommended for the Raritan Bay disposal site is a floating dike. This type of dike is built on top of the soft foundation soils without causing a bearing capacity failure in the foundation materials. Use of a reinforcing fabric with the ability to withstand high tensile stresses and to maximize frictional forces at the soil-fabric interface will allow use of side slopes as steep as 1V:4H instead of the flatter slopes required for nonreinforced dikes. The floating dikes which do not displace foundation soils will require less construction material, and thus the cost will be significantly reduced.

48. For the floating dike scenario which is shown in Figure D6, a fill volume of 55 yd^3/lin ft of dike would be required to construct the dike to a crest elevation of +10 ft mlw. Slope protection must be used on the exterior of all constructed dikes except those dikes adjacent to the existing land mass. Details of the recommended construction procedure are given in Appendix D.

49. The only dike designs provided in the GL report had dike crest elevations of +10 ft mlw (see Appendix D). It is assumed, although not stated in the GL report, that this dike crest elevation is a compromise height based upon foundation soil-bearing capacity and other factors in addition to storm-surge elevations since a crest elevation of +10 ft mlw does not allow for the recommended 2 ft of freeboard above even a 1-year return interval storm surge.

This dike crest elevation and the resulting cost estimate could be modified through an additional geotechnical analysis to increase or decrease the dike height as deemed appropriate for various containment/wetland creation scenarios.

PART III: STORAGE CAPACITY EVALUATION FOR CONTAINMENT AREA CREATION

50. Placement of dredged material in confined disposal sites (containment areas) is being considered as an alternative to open water disposal for contaminated sediments encountered on dredging projects in the New York Harbor area. This disposal option, however, is not limited exclusively to contaminated sediments; it may also be used for disposal of clean (uncontaminated) sediments.

51. Four sites are being considered for confined disposal of dredged material. These sites are Bowery Bay, Flushing Bay, Newark Bay, and Raritan Bay. All four sites may be used to contain either contaminated dredged material or uncontaminated dredged material. Therefore two possible scenarios of containment area usage will be considered in this section of the report: (a) disposal of uncontaminated dredged material; and (b) disposal of contaminated dredged material.

52. The following paragraphs discuss general site conditions which must be considered for both the uncontaminated and the contaminated scenarios. The capacities of individual sites for containing dredged material are then presented.

General Site Conditions

53. In the following paragraphs, the general site conditions which may affect performance and/or analysis of the disposal sites are discussed. In some instances, no site-specific data are available for certain parameters. Therefore assumptions had to be made based upon the limited existing data as well as experience with other similar sites and materials.

Tides

54. The average tidal fluctuation in the New York Harbor area is approximately 5 ft. For purposes of this study, the datum is mean low water (el 0 ft mlw), and mean high water is taken as el +5 ft mlw. This information was obtained from National Oceanic and Atmospheric Administration (NOAA) tide tables (1984).

Retaining dikes

55. The retaining dikes at each site should be constructed as described in Part II of this report and are assumed, for this analysis, to have the configurations shown in Part II. It should be noted that the dike crest elevations used for Bowery Bay, Flushing Bay, and Raritan Bay are el +10 ft mlw. At Newark Bay, the dike crest is assumed to be at el +12 ft mlw. The GL initially assumed el +10 ft mlw to be an adequate dike crest elevation and proceeded with three dike designs. The New York District then requested that a higher dike crest elevation be used; this resulted in the use of el +12 ft mlw crest elevation at the one remaining site which was the Newark Bay site.

Climatological data

56. Use of climatological data is necessary whenever dredged material may be subjected to evaporative drying. The data are needed in this analysis since it is desired to store as much dredged material as possible within each containment area and since mean high water is 5 to 7 ft below the dike crest elevation at each site, thus subjecting upper lifts of dredged material to evaporative drying.

57. The monthly averages for rainfall and evaporation in the New York Harbor area were calculated. The rainfall data were obtained from the NOAA (1980) and were averaged for a period of 50 years. Evaporation data were averaged over a 30-year time period (Haliburton 1978). The data utilized in the analysis are shown in Table 5.

Foundation soil conditions

58. Each of the four sites under consideration is underlain by a relatively thick compressible foundation soil stratum as shown in Part II of this report. This compressible material must be considered when the storage capacity of a containment area is being assessed because consolidation of this layer can significantly affect the long-term capacity of the site.

59. Because no consolidation data were available for the foundation soils at any of the four sites, the most representative compressibility data available were used. The void ratio-effective stress and void ratio-permeability relationships for the assumed representative foundation soil are tabulated in Appendix E. This compressible foundation soil was considered to extend to the appropriate depth at each of the containment areas.

Sediments

60. According to information received from the New York District, various sediments are expected to be deposited in specific containment areas. The sediment to be placed in a particular containment area would differ depending upon whether contaminated or uncontaminated sediments were to be dredged. Therefore, different sediment compressibility data must be used for the various analyses.

61. Four typical sediments were selected to be representative of dredged materials which might be placed in the individual containment areas. The sediments are identified by alphabetic characters A through D, and their physical properties are given in Appendix F. Sediments assumed to be placed in the sites for each scenario are shown in Table 6.

62. The quantity of dredged material to be placed in each containment area is dependent upon the particular scenario and site under consideration. The thickness of the dredged material layer deposited in a containment area depends upon the quantity of material placed and the surface area of the containment area. For each site, the sediment properties to be used, the quantity of material (bin yardage), and the resulting lift thickness after hydraulic pumping are listed in Table 6. It should be noted that the lift thickness is not obtained directly by dividing the volume of material deposited by the surface area of the disposal site. Several intermediate calculations are required to account for the change in dredged void ratio between the transport barge and the containment area. The void ratio of all sediments was assumed to be 5.0 as the material existed in the barge. After the material was pumped into the containment area, the void ratio was considered to be that which exists in the material at zero effective stress (e_{oo}). This value is equivalent to the largest void ratio shown in Appendix F for the sediment of interest.

Disposal operations

63. Because specific dredging schedules were not available at the time of this study, certain assumptions were required. It was generally assumed that dredged material was deposited into each containment area only once per year. In some cases it was necessary to simulate the placement of annual quantities of dredged material in semiannual increments to prevent overtopping of the dikes. If the annual quantity of material was deposited incrementally during two disposal operations instead of during only one operation, the

thickness of each lift of material would be smaller although the annual applied thickness would remain constant.

64. A second assumption was made regarding the time of year at which the dredging/disposal operation would begin. It was assumed that all dredging operations would begin in early January. This assumption is significant only because the evaporative drying rates vary during different seasons of the year. The most effective drying period in the New York Harbor area is May to September whereas no significant evaporative drying will occur during the period of November through March. If the dredged material is allowed to dry for a period of one year, then the effect of timing on initiation of dredging is insignificant.

65. An additional assumption was made regarding the time which would elapse between initiation of disposal operations and decantation of ponded surface water/beginning of evaporative drying in the disposal site. A period of 90 days (3 months) was assumed for all cases in which evaporative drying would occur. Drying of the dredged material surface was allowed only when the surface was above mean high water (el +5 ft mlw). This elevation was taken for the elevation of a permanent water table within the deposited dredged material since it represents a worst case condition, i.e., the case in which the least gain in storage capacity would be realized from evaporative drying. Actual water table conditions could not be predicted since information was not available for site operating procedures, permeability of dikes, permeability of foundation soils, and general hydrologic conditions at the site.

Site-Capacity Model

66. A model for predicting site capacity was used which incorporated a finite strain consolidation technique (Cargill 1985). The governing equation for finite strain consolidation theory is based on the continuity of fluid flow in a differential soil element, Darcy's law, and the effective stress principle, similar to the conventional consolidation theory (Gibson, England, and Hussey 1967). However, finite strain theory can additionally consider vertical equilibrium of the soil mass, place no restriction on the form of the stress-strain relationship, allow for variable coefficient of permeability, and accommodate any degree of strain. The governing equation is:

$$\left(\frac{\gamma_s}{\gamma_w} - 1\right)\frac{d}{de}\left[\frac{k(e)}{1 + e}\right]\frac{\partial e}{\partial z} + \frac{\partial}{\partial z}\left[\frac{k(e)}{\gamma_w(1 + e)}\;\frac{d\sigma'}{de}\;\frac{\partial e}{\partial z}\right] + \frac{\partial e}{\partial t} = 0 \qquad (1)$$

where

γ_s = unit weight of solids

γ_w = unit weight of water

e = void ratio

$k(e)$ = soil permeability as a function of void ratio

z = vertical material coordinate measured against gravity

σ' = effective stress as a function of void ratio

t = time

This equation is well suited for the prediction of consolidation in thick deposits of very soft dredged materials since it accounts for the large strains and nonlinear soil properties inherent in these materials.

67. The removal of water by desiccation from a normally consolidating dredged material layer will result in formation of a surface crust; this in turn will cause additional consolidation due to the surcharge created by crust formation. Since surface drying may be significant between disposal operations, it is essential to incorporate predictions of desiccation settlement in evaluations of disposal site capacity.

68. An empirical description of the desiccation has been developed in terms of water balance in the upper portion of dredged material layers (Cargill 1985). Procedures for calculation of soil evaporation rates and depths of influence have been developed. Site-specific climatic conditions are incorporated in the analysis procedures. The predictive model developed utilizes void ratios instead of water contents in order to be compatible with the consolidation model.

69. Both the finite strain consolidation model and the empirical desiccation model have been programmed for computer solution (Cargill 1985). The program Primary Consolidation and Desiccation of Dredged Fill (PCDDF) incorporates an explicit finite difference mathematical approximation of the governing differential equation to describe the consolidation process. Monthly adjustments in the top boundary condition and location are made to account for the amount of desiccation which has occurred. In addition to material

settlement which comes from a calculation of void ratio distribution, the program also calculates the distribution of stresses and pore pressures throughout the dredged material layer.

70. This computer program was initially written for use in confined upland disposal sites where a temporary perched water table, not a permanent water table, existed. Because the program was not developed for the particular case which this report addresses, some manipulations and additional runs of the program were required to obtain the desired results.

Uncontaminated Scenario

71. The uncontaminated scenario assumes no ocean disposal of dredged material is permitted and all sediments dredged in the New York Harbor area would have to be deposited in confined disposal sites. The four containment areas available for such disposal, Bowery Bay, Flushing Bay, Newark Bay, and Raritan Bay, were discussed in Part II of this report.

72. In order to analyze the disposal site capacity for this scenario, it was assumed that the volume of material dredged in 1983 was representative of the annual quantities of sediment to be dredged for maintenance purposes. It was also assumed that material from a given dredging project would be placed in the closest containment area when possible while maintaining equal (ultimate) disposal quantities in each of the four sites. The quantity of dredged material to be placed in each containment area was provided by the New York District.

Bowery Bay

73. The annual quantity of uncontaminated dredged material to be placed at the Bowery Bay site is 1.13 million yd^3 (bin yardage). This quantity represents the volume of material placed from both Federal and private dredging projects. The material will be clamshelled and placed in barges for transport to the Bowery Bay disposal site, where it will be hydraulically pumped into the containment area. Sediment A was assumed to be representative of the uncontaminated dredged material to be placed in the Bowery Bay site.

74. Placement of 1.13 million yd^3 of dredged material in the 65-acre (2.85×10^6 ft^2) containment area would result in a single initial lift thickness of 17.0 ft. Because a lift thickness of this magnitude would immediately fill the containment area and possibly overtop the dikes, annual placement of

one 8-ft lift and one 9-ft lift at 6-month intervals was used in the mathematical analysis of site capacity. This simulates placement of the correct quantity of material on an annual basis and has no long-term effect on the dredged material surface elevation.

75. Results of the analysis utilizing the computer code PCDDF indicate that the site would be filled to capacity during the second year of disposal operations. The filling simulation is shown in Figure 1; the dark bar along the horizontal axis indicates the period during which the dredged material surface was undergoing evaporative drying while above the existing water table. With judicial placement of the dredged material, it should be possible to place the entire 9-ft lift during the second year but only a portion (approximately one-half) of the 8-ft lift could be placed before the site would be filled to capacity. This results in ultimate placement of two 9-ft lifts, one 8-ft lift, and one 4-ft (maximum) lift, or a total volume of approximately 2.00 million yd^3 of uncontaminated dredged material.

Flushing Bay

76. The annual quantity of uncontaminated dredged material to be placed at the Flushing Bay site is approximately 1.10 million yd^3 (bin yardage). This quantity represents the volume of material placed from both Federal and private dredging projects. The material will be either: (a) clamshell dredged and barged to the site where it will be rehandled; or (b) hydraulically dredged and pumped directly into the containment area. Sediment A was assumed to be representative of the uncontaminated dredged material to be placed in the Flushing Bay site.

77. Placement of approximately 1.10 million yd^3 of dredged material in the 54 acre (2.34×10^6 ft^2) containment area would result in a single initial lift thickness of 20.0 ft. Because a lift thickness of this magnitude would overtop the retaining dikes, annual placement of two 10.0-ft lifts at intervals of six months was used in the mathematical analysis of site capacity. This simulates placement of the correct quantity of material on an annual basis and has no long-term effect on the dredged material surface elevation.

78. Results of the analysis utilizing the computer code PCDDF indicate that the site would be filled to capacity during the second year of disposal operations. The filling simulation is shown in Figure 2; the dark bar along the horizontal axis indicates the period during which the dredged material surface was undergoing evaporative drying while above the existing water

table. Placement of the first 10.0-ft lift during the second year would result in overtopping of the dikes. At most, approximately 5 ft of the 10.1-ft lift could be placed at this time. This results in ultimate placement of two 10.1-ft lifts and one 5-ft lift for a total of approximately 1.38 million yd^3 of uncontaminated dredged material at Flushing Bay.

Newark Bay

79. The annual quantity of uncontaminated dredged material to be placed at the Newark Bay site is approximately 1.38 million yd^3 (bin yardage). This quantity represents the volume of material placed from both Federal and private dredging projects. The material will be either: (a) clamshell dredged and barged to the site where it will be rehandled; or (b) hydraulically dredged and pumped directly into the containment area. Sediment B was assumed to be representative of the uncontaminated dredged material to be placed in the Newark Bay site.

80. Placement of 1.38 million yd^3 of dredged material in the 156-acre (6.79×10^6 ft^2) containment area would result in a single initial lift thickness of 10.8 ft. Simulation of placement of this lift thickness was possible for the first 2 years after which lift thicknesses of 5.4 ft applied twice yearly were necessary to prevent overtopping of the dikes. The latter simulates placement of the correct quantity of material on an annual basis and has no long-term effect on the dredged material surface elevation.

81. Results of the analysis utilizing the computer code PCDDF indicate that the site would be filled to capacity during the fourth year of disposal operations. The filling simulation is shown in Figure 3; the dark bars along the horizontal axis indicate the periods during which the dredged material surface was undergoing evaporative drying while above the existing water table. Placement of the entire first 5.4-ft lift during the fourth year could probably be accomplished by judicial disposal of the material, but only an insignificant amount of the following 5.4-ft lift could be placed. This results in ultimate placement of two 10.8-ft lifts and three 5.4-ft lifts or a total volume of approximately 4.8 million yd^3 of uncontaminated dredged material.

Raritan Bay

82. The annual quantity of uncontaminated dredged material to be placed at the Raritan Bay site is approximately 0.57 million yd^3 (bin yardage). This quantity represents the volume of material placed from both Federal and

private dredging projects. The material will be either: (a) clamshell dredged and barged to the site where it will be rehandled; or (b) hydraulically dredged and pumped directly into the containment area. Sediment C was assumed to be representative of the uncontaminated dredged material to be placed in the Raritan Bay site.

83. Annual placement of approximately 0.57 million yd^3 of dredged material in the 335 acre (14.6×10^6 ft^2) containment area would result in a 1.8-ft lift thickness. This thin lift caused no problems with dike overtopping and was, therefore, used as an annual 1.8-ft lift throughout the analysis period.

84. Results of the analysis utilizing the computer code PCDDF indicate that the site would have a service life in excess of 20 years. The filling simulation is shown in Figure 4. As shown in this figure, the first eight annual lifts of 1.8 ft are subjected to self-weight consolidation only since the dredged material surface has not reached sufficiently high above the water table to desiccate. All lifts placed after $t = 8$ years are subjected to evaporative drying for periods of time represented by the dark bar shown along the horizontal axis. Considering a 20-year time period, ultimate placement of approximately 11.4 million yd^3 of uncontaminated dredged material would be accomplished at Raritan Bay.

Contaminated Scenario

85. The contaminated scenario assumes ocean disposal of dredged material is allowed, and most of the sediments dredged from the New York Harbor area could be placed in ocean disposal sites. Any contaminated sediments would need to be placed in confined disposal sites or placed in ocean disposal sites and properly capped. For this scenario, it is assumed that all of the contaminated sediments will be deposited in confined disposal sites, and the sites will be used exclusively for containment of contaminated sediments. The four containment areas available for such disposal are Bowery Bay, Flushing Bay, Newark Bay, and Raritan Bay; these sites were discussed in Part II of this report.

86. In order to analyze the disposal site capacity for this scenario, it was assumed that the volume of material dredged in 1983 was representative of the annual quantities of maintenance material (sediment) to be dredged. It

was further assumed that 5 percent of this material, or 0.21 million yd^3, was totally unacceptable for ocean disposal and would therefore require placement in confined disposal sites. In addition, it was assumed that the 0.47 million yd^3 of material which required capping in 1983 was representative of the annual quantity of contaminated material requiring isolation; this material would also be placed in confined disposal sites. Therefore, the total quantity of contaminated dredged material to be placed in containment areas was assumed to be 0.68 million yd^3. This material was assumed to be evenly distributed to the four containment areas under study. The assumptions utilized for this scenario were provided by the New York District.

87. The quantity of contaminated dredged material to be placed at each site is 169,000 yd^3 (bin yardage). This quantity represents the volume of material placed from both Federal and private dredging projects. The material will be hydraulically pumped into the containment areas. Sediment D is assumed to be representative of the contaminated dredged material to be placed in each of the four containment areas.

Bowery Bay

88. Annual placement of 169,000 yd^3 of contaminated dredged material in the 65 acre (2.85×10^6 ft^2) containment area would result in a lift thickness of 3.2 ft. This thin lift was used successfully throughout the analysis period.

89. Results of the analysis utilizing the computer code PCDDF are shown in Figure 5. Two curves are shown in this figure; they represent a worst case condition and a best case condition. The worst case is represented by the upper curve and indicates a service life of approximately 9 years. The best case is represented by the lower curve which indicates a service life of approximately 20 years.

90. The worst case condition simulates the situation in which no desiccation of the dredged raterial surface is allowed to occur. For this case it is assumed that a pond of surface water is maintained above the dredged material. This situation is sometimes preferable to allowing desiccation and the subsequent oxidation/mobilization of contaminants which has been found to occur with certain pollutants. If a pond of surface water is maintained for management of contaminants, the ultimate capacity/service life of the containment area will be minimized. In this worst case, a maximum of 10 annual disposal operations would fill the site to capacity. This would result in

ultimate placement of 1.69 million yd^3 of contaminated sediments at the Bowery Bay containment area.

91. The best case condition simulates the situation in which desiccation of the dredged material surface is allowed to occur. This would be the preferred way to operate the site, from a site capacity perspective, since it would maximize the ultimate capacity/service life of the containment area. This method of operation should be allowed only if chemical analyses and containment area water balance/water movement studies are performed and indicate no problem with contaminant availability in the site or movement out of the site. In this best case, a maximum of 21 annual disposal operations would fill the site to capacity. This would result in ultimate placement of 3.55 million yd^3 of contaminated sediments at the Bowery Bay containment area as compared to 1.69 million yd^3 if no desiccation were permitted to occur.

Flushing Bay

92. Annual placement of 169,000 yd^3 of contaminated dredged material in the 54 acre (2.34×10^6 ft^2) containment area would result in a lift thickness of 3.8 ft. This thin lift was used successfully throughout the analysis period.

93. Results of the analysis utilizing the computer code PCDDF are shown in Figure 6. Two curves are shown in this figure; they represent a worst case condition and a best case condition. The worst case is represented by the upper curve and indicates a service life of approximately 6 years. The best case is represented by the lower curve which indicates a service life of about 16 years.

94. The worst case condition simulates the situation in which no desiccation of the dredged material surface is allowed to occur. For this case it is assumed that a pond of surface water is maintained above the dredged material. This situation is sometimes preferable to allowing desiccation and the subsequent oxidation/mobilization of contaminants which has been found to occur with certain pollutants. If a pond of surface water is maintained for management of contaminants, the ultimate capacity/service life of the containment area will be minimized. In this worst case, a maximum of seven annual disposal operations would fill the site to capacity. This would result in ultimate placement of 1.18 million yd^3 of contaminated sediment at the Flushing Bay containment area.

95. The best case condition simulates the situation in which desiccation of the dredged material surface is allowed to occur. This would be the preferred way to operate the site, from a site capacity perspective, since it would maximize the ultimate capacity/service life of the containment area. This method of operation should be allowed only if chemical analyses and containment area water balance/water movement studies are performed and indicate no problem with contaminant availability in the site or movement out of the site. In this best case, a maximum of 17 annual disposal operations would fill the site to capacity. This would result in ultimate placement of 2.87 million yd^3 of contaminated sediments at the Flushing Bay containment area.

Newark Bay

96. Annual placement of 169,000 yd^3 of contaminated dredged material in the 156 acre (6.79×10^6 ft^2) containment area would result in a lift thickness of 1.4 ft. This thin lift was used successfully throughout the analysis period.

97. Results of the analysis utilizing the computer code PCDDF are shown in Figure 7. Two curves are shown in this figure; they represent a worst case condition and a best case condition. The worst case is represented by the upper curve and indicates a service life of approximately 23 years. The best case is represented by the lower curve which indicates a service life approaching 40 years.

98. The worst case condition simulates the situation in which no desiccation of the dredged material surface is allowed to occur. For this case it is assumed that a pond of water is maintained above the dredged material. This situation is sometimes preferable to allowing desiccation and the subsequent oxidation/mobilization of contaminants which has been found to occur with certain pollutants. If a pond of surface water is maintained for management of contaminants, the ultimate capacity/service life of the containment area will be minimized. In this worst case, a maximum of 24 annual disposal operations would fill the site to capacity. This would result in ultimate placement of 4.06 million yd^3 of contaminated sediments at the Newark Bay containment area.

99. The best case condition simulates the situation in which desiccation of the dredged material surface is allowed to occur. This would be the preferred way to operate the site from a site capacity perspective since it

would maximize the ultimate capacity/service life of the containment area. This method of operation should be allowed only if chemical analyses and containment area water balance/water movement studies are performed and indicate no problem with contaminant availability in the site or movement out of the site. In this best case, a maximum of approximately 40 annual disposal operations would fill the site to capacity. This would result in ultimate placement of approximately 6.76 million yd^3 of contaminated sediments at the Newark Bay containment area.

Raritan Bay

100. Annual placement of 169,000 yd^3 of contaminated dredged material in the 335 acre (14.6×10^6 ft^2) containment area would result in a lift thickness of 0.6 ft. This thin lift was used successfully throughout the analysis period.

101. Results of the analysis utilizing the computer code PCDDF are shown in Figure 8. Because of the extremely thin lift thickness, the dredged material surface does not rise significantly above the water table during the 20-year analysis period; therefore only one curve is shown for this containment area. The service life of Raritan Bay for containment of contaminated dredged material is greater than 20 years and is projected to be approximately 35 years. This results in ultimate placement of approximately 5.92 million yd^3 of contaminated sediments at the Raritan Bay containment area.

Containment Area Monitoring

102. The containment areas should be monitored periodically in order to document the condition of dikes and the rate at which the site is being filled for either the contaminated or uncontaminated scenario. The dike condition should be visually checked on a quarterly basis and after any major storms to determine if maintenance is required to maintain the integrity of the dikes. The elevation of the dredged material surface should be determined by annual surveying. This elevation should then be compared to the predicted surface height in order to evaluate/modify the projected service life of the individual containment areas.

PART IV: STORAGE CAPACITY EVALUATIONS FOR WETLAND STABILIZATION

103. The creation of wetlands at dredged material disposal sites is a proven technology which is feasible from both the environmental and engineering perspectives. Minimum site-specific requirements that must be met for salt marsh development include: (a) low to moderate wave energy climates, including ship traffic wakes; (b) suitable substrate environmental conditions such as tolerable salinity and containment levels; (c) means of placing dredged material to achieve an intertidal level; (d) accessibility over most or all of the site for planting and management purposes; and (e) protection of the newly established (planted) marsh until the substrate has established.

104. Dredged material which is not heavily contaminated can be used for development of a salt marsh as well as for other productive uses. Sandy dredged material lends itself to easier development uses because it is less susceptible to resuspension in the water column, or erosion by wave energy is more likely to form a suitable intertidal bed for developing marshes. However, any type of sediment that can be temporarily confined to allow plant development and substrate stabilization has potential for marsh development and other beneficial uses.

105. Wetlands development is one of the dredged material disposal alternatives available to the New York District at the proposed disposal sites in the New York Harbor area. The three sites amenable to wetland creation are Bowery Bay, Flushing Bay, and Raritan Bay. The Newark Bay site cannot be utilized as a wetland creation area because it is located in the center of an industrialized zone (Port Newark) and is subjected to wave action from intense ship traffic. It should be noted that since the three potential wetland sites will be filled with silty dredged material, some permanent retaining structures will be necessary to hold the dredged material at an intertidal level.

106. Dredged material to be used for creation of wetlands must be uncontaminated. This is necessary for two reasons: (a) salt-marsh plants will not have acceptable survival rates if highly contaminated dredged material is used, i.e., the toxicity level is too high to sustain plant growth; and (b) establishment of a marsh requires intertidal flushing which in itself precludes use of contaminated dredged material.

Procedures for Wetlands Stabilization

107. Development of successful wetlands can be accomplished by following four basic steps. These are: (a) construction of appropriate retaining structures; (b) placement of dredged material to proper elevation for marsh grass survival; (c) planting of appropriate marsh grasses; and (d) expedient and proper breaching of the retaining dikes.

108. Retaining structures should be built at each site in accordance with guidance provided in Part II and Appendices A-D of this report. These structures will be required to contain the fine-grained material which is to be placed at each of the proposed disposal sites until some consolidation and establishment of salt-marsh grass has occurred.

109. Dredged material should be placed at an intertidal level (el +3 to +5 ft mlw) throughout the disposal site, placing material first in the back reaches and moving toward the front or open side of the site after the back areas are filled. The site should be filled completely to an intertidal level, allowing for settling and subsidence of material as it stabilizes. The character and final topography of the salt marsh will develop after the dikes have been breached and intertidal flow initiated. The material should be at a depth of approximately 1 to 2 ft below mean high tide when stabilized to allow for plant growth.

110. The entire site should be planted with smooth cordgrass (*Spartina alterniflora*) placed on 1-m centers and planted down to 2 ft below mean high tide to ensure greater plant survival of sprigs. Cost of salt-marsh development, excluding all structures and material placement, and only including obtaining, maintaining, planting, and replacing propagules of smooth cordgrass would range from $4,000 to $6,000 an acre in the New York area depending upon working conditions and problems encountered. One-meter centers should be adequate for site stabilization within five years. Other species such as saltmeadow cordgrass (*Spartina patens*) and saltgrass (*Distichlis spicata*) will colonize the site naturally as conditions become more favorable for high marsh zone species.

111. The retaining structure should be breached during or immediately after planting the site to allow for intertidal flow across the planted site. The breach or breaches should be located at places with least erosion potential and should not be breached below mean low tide lines. Several

breaches strategically placed may lessen erosion at these areas. It is to be expected that tidal creeks will form at each of the breaches; they will extend out into the marsh.

General Site Conditions

112. In the following paragraphs, the site conditions which may affect performance and/or analysis of the wetlands are discussed. In some instances, no site-specific data are available for certain parameters. Therefore, assumptions had to be made based upon the limited existing data as well as experience with similar sites and materials.

113. Because wetlands can exist and thrive only in low wave energy environments, only the proposed Bowery Bay, Flushing Bay, and Raritan Bay disposal sites were considered for wetland stabilization. The Newark Bay site was eliminated because of its location in a heavily industrialized area near Port Newark. The three sites considered for wetland stabilization are in relatively low energy environments according to information provided by the New York District; any necessary protection of the new marsh from wave action will be provided by the portions of the dike remaining after appropriate breaches have been made.

114. As discussed in Part III, the average tidal fluctuation in the New York Harbor area is approximately 5 ft. Datum is taken at mean low water (el 0 ft mlw), and mean high water is taken at el +5 ft mlw for purpose of this study.

Retaining dikes

115. Retaining dikes should be constructed at each disposal site as described in Part II of this report. Details of both the site location and dike design were discussed previously. The dike crest elevation used at each site for the wetland analysis is el +10 ft mlw.

Foundation soil conditions

116. Because foundation soil compressibility parameters were not available for the three sites under consideration, the most representative compressibility data available were used. The void ratio-effective stress and void ratio-permeability relationships for the assumed foundation soil are tabulated in Appendix E.

Sediment data

117. For the creation of wetland areas, it is assumed that clean (uncontaminated) sediments are to be used. The quantity of this material available for use on an annual basis is 1.377 million yd^3 (bin yardage) and will be divided equally among the three sites (459,000 yd^3/site). This information was provided by the New York District.

118. Since data on sediment water content, void ratio, or other associated parameters were not available, a void ratio of 5.0 was assumed to be typical of the material as it would exist in the barge. This value is believed to be representative of material clamshelled into a transport barge and is consistent with both the limited available data from this area and empirical evidence from other disposal operations.

119. Establishment of wetlands requires careful placement of dredged material to attain a surface elevation which is 1 to 2 ft below mean high water. Therefore, the dredged material should be placed in such a manner that the final elevation is approximately el +4 ft mlw. By choosing this higher target elevation, any consolidation occurring in the long term, i.e., after approximately 20 years, will not cause such a significant reduction in surface elevation as to affect the nature of the salt marsh.

Disposal operations

120. Because no information was available on the dredging schedule, it was assumed, for simulation purposes, that: (a) the dredged material was placed once per year; and (b) the disposal operation occurred in January of each year. The first assumption will only affect the short term surface elevation within the disposal site; it will have no effect on prediction of the final surface elevation. The second assumption will have no effect on the analysis since there is no desiccation; therefore, the disposal operations could occur at any time during the year without affecting the results obtained in this study.

121. Discussions of the site-specific details of wetland stabilization at each of the three proposed sites are given in the following paragraphs. This information should provide an appropriate level of detail for planning purposes.

Bowery Bay

Material placement

122. After completion of dike construction, dredged material should be placed in the disposal site by hydraulic pipeline dredge. The pipeline discharge point(s) should be located along the southern side of the site (near the fuel storage area and the Marine air terminal). By placing the material from the southern side of the site, a gradual sloping of the final dredged material surface from south (higher elevation) to north (lower elevation) will be attained. This will allow more complete intertidal flushing of the site and will minimize any potential erosion which might occur after breaching of the dike.

123. The quantity of dredged material to be placed for wetland creation at the Bowery Bay site is 459,000 yd^3 (bin yardage) annually. The average surface area contained within the retaining dikes (i.e., surface area remaining at the site after dike construction) is approximately 65 acres (2.85×10^6 ft^2). This combination of disposal site surface area and quantity of dredged material results in an annual lift thickness of approximately 6.8 ft. Material classification and consolidation properties used in this analysis are given in Appendix F.

124. Results of the filling simulation are shown in Figure 9. In order to fill this site to the required elevation for wetland creation, five annual disposal operations each involving placement of 459,000 yd^3 of material would be required. This results in ultimate placement of approximately 2.3 million yd^3 (bin yardage) of dredged material. The disposal operations were assumed to occur at times $t = 0, 1, 2, 3$, and 6 years ; judicial placement of material at $t = 6$ years will be required to prevent overtopping of the retaining dikes. Placement of the dredged material at these times was used to prevent: (a) overtopping of the dikes; and (b) drying of the dredged material surface which would be deleterious to wetland creation.

125. For the periods of time when the dredged material surface is above mean high water, it would be advantageous to maintain a small pond of water on the dredged material surface to prevent desiccation. This would ensure that the dredged material surface would remain in a condition amenable to wetland creation. If the mobilization/demobilization costs are not prohibitive, it might be advantageous to place smaller quantities of dredged material at

frequent time intervals to avoid creating a situation in which the dredged material surface remains well above the intertidal zone for extended periods of time as it does after placement of 6.8 ft lift at $t = 6$ years.

Postdisposal activities

126. After disposal is completed and the dredged material has reached a proper elevation (about 15 years after initial disposal), the site should be planted with smooth cordgrass (*S. alterniflora*). The plants should be placed on 1-m centers, and their root mass should be planted to a depth of 2 ft below mean high tide. For this disposal site, the cost of planting the finished wetland would be approximately $260,000 to $400,000.

127. The dike should be breached after planting of the wetland is completed. At this site, the breaches would be made in the recently constructed dikes along the north and northwest sides of the site. It is preferable to make several breaches instead of a single breach at low wave energy locations in order to reduce flow velocities and wave action into the wetland. Observation of the site during dike construction and dredged material placement should allow identification of potential breach locations.

Flushing Bay

Material placement

128. After completion of dike construction, dredged material should be placed in the disposal site by hydraulic pipeline dredge. The pipeline discharge point(s) should be located along the southern side of the site adjacent to Runway 13-31 at La Guardia Airport. By placing the material along this side of the site, a gradual slope of the final dredged material surface from south (higher elevation) to north (lower elevation) will be attained. This will allow thorough intertidal flushing of the site and will minimize any potential erosion which might occur after breaching of the dike.

129. The quantity of dredged material to be placed for wetland creation at the Flushing Bay site is 459,000 yd^3 (bin yardage) annually. The average surface area contained within the retaining dikes (i.e., surface area remaining at the site after dike construction) is approximately 54 acres (2.34×10^6 ft^2). The combination of disposal site surface area and quantity of dredged material results in a lift thickness of approximately 8.4 ft.

Material classification and consolidation properties used in this analysis are given in Appendix F.

130. Results of the filling simulation are shown in Figure 10. In order to fill this site to the required elevation for wetland creation, three annual disposal operations involving placement of 459,000 yd^3 and one operation involving placement of 357,000 yd^3 would be required. This results in ultimate placement of approximately 1.73 million yd^3 (bin yardage) of dredged material. The disposal operations were assumed to occur at $t = 0, 1, 2,$ and 6 years, with the placement of $t = 6$ years involving the smaller quantity of material. Placement of the dredged material at these times was used to prevent: (a) overtopping of the dikes; and (b) drying of the dredged material surface which would be deleterious to wetland creation.

131. For the periods of time when the dredged material surface is above mean high water, it would be advantageous to maintain a small pond of water on the dredged material surface to prevent desiccation. If the mobilization/demobilization costs are not prohibitive, it might be advantageous to place smaller quantities of dredged material at frequent time intervals to avoid creating a situation in which the dredged material surface remains well above the intertidal zone for extended periods of time as it does after placement of the 6.6-ft lift at $t = 6$ years.

Postdisposal activities

132. After about 14 years when disposal is completed and the dredged material has reached a proper elevation, the site should be planted with smooth cordgrass (*S. alterniflora*). The plants should be placed on 1-m centers, and their root mass should be planted to a depth of 2 ft below mean high tide. For this disposal site, the cost of planting the finished wetland would be approximately $216,000 to $324,000.

133. The dikes should be breached after planting of the wetland is completed. At this site, the breaches would be made in the recently constructed dikes along the east, north, and/or west sides of the disposal site. It is preferable to make several breaches instead of a single breach at selected low wave energy locations in order to reduce flow velocities and wave action into the wetland. Observation of the site during dike construction and dredged material placement should allow identification of potential breach locations.

Raritan Bay

Material placement

134. After completion of dike construction, dredged material should be placed in the disposal site by hydraulic pipeline dredge. The pipeline discharge point(s) should be located along the side adjacent to the existing shoreline. By placing the material along this side of the site, a gradual slope of the final dredged material surface from west (higher elevation) to east (lower elevation) will be attained. This will allow thorough intertidal flushing of the site and will minimize any potential erosion which might occur after breaching of the dike.

135. The quantity of dredged material to be placed for wetland creation at the Raritan Bay site is 459,000 yd^3 (bin yardage) annually. The average surface area contained within the retaining dikes (i.e., surface area remaining at the site after dike construction) is approximately 335 acres (14.6×10^6 ft^2). The combination of disposal site surface area and quantity of dredged material results in a lift thickness of approximately 1.4 ft. Material classification and consolidation properties used in the analysis are given in Appendix F.

136. Results of the filling simulation are shown in Figure 11. In order to fill this site to the required elevation for wetland creation, 13 annual disposal operations each involving placement of 459,000 yd^3 would be required. This results in ultimate placement of approximately 6.0 million yd^3 (bin yardage) of dredged material. The disposal operations were assumed to occur at times $t = 0$ through 13 years inclusive. Because of the thin lifts of dredged material placed at Raritan Bay, there will be no problem with overtopping of the dikes or drying of the dredged material surface.

Post-disposal activities

137. After about 16 years when disposal is completed and the dredged material has reached the proper elevation, the site should be planted with smooth cordgrass (*S. alterniflora*). The plants should be placed on 1-m centers, and their root mass should be planted to a depth of 2 ft below mean high tide. For this disposal site, the cost of planting the finished wetland would be approximately \$1.34 million to \$2.1 million.

138. The dikes should be breached after planting of the wetland is completed. At this site, the breaches should be made in the recently constructed

dikes along the northern and eastern sides of the disposal site. It is preferable to make several breaches, instead of a single breach, at selected low wave energy locations in order to reduce flow velocities and wave action into the wetland. Observation of the site during dike construction and dredged material placement should allow identification of potential breach locations.

Wetland Monitoring

139. The wetland sites should be monitored in order to document the development of the planted salt marshes. This is a necessary phase of any environmental project regardless of site and should be conducted prior to, during, and following wetlands development. In this discussion, monitoring will only address those organisms affected by site development as a wetland.

140. Marshes made of smooth cordgrass planting should be observed at least monthly after initial planting for about 6 months, then semiannually for 2 years, and afterwards, annually. Survival, growth, and reproduction can easily be determined by the establishment of permanent nondestructive plots interspersed throughout the new marsh. Measurement of the three success indications can be compared from observation to observation. Root and shoot biomass should be sampled in other plots within the containment area, not in the permanently established ones. This is necessary in order to determine the sites' progressive movements towards a salt-marsh soil profile with dense root mats, a natural occurrence, but one in which progression varies from region to region and site to site.

141. Wildlife use of a site should be adequately measured by simple, seasonal observations (four times a year). Colonization, breeding, migratory, and loafing records for bird and mammal species should be kept in continuing site-succession stage files in New York District. Clapper rails, tern species, and other species of special interest should be especially noted. Comparisons of use and colonization from observation to observation will give a picture of marsh development both as documentation of success and as records of site-specific problems and opportunities that may have arisen as the site was being developed.

142. Benthos at a wetlands site should be adequately measured according to the same timetable (seasonal). The use of the site as a fish nursery should also be determined and documented.

PART V: ECONOMIC ANALYSIS

143. In order to determine the feasibility of constructing the proposed containment areas or wetlands, an economic analysis should be made of all potential disposal options. Cost comparisons between disposal options should consider costs for site preparation, dredged material transportation and disposal costs, site maintenance/upkeep, and any other costs which would be incurred as a result of a particular disposal option. In addition to comparisons of total costs, comparisons should also be made between costs per unit volume of dredged material contained in the various sites.

144. Because of the preliminary nature of this study and the lack of specific data on sediment locations and dredging operations, the cost comparisons made in this section will consider only the costs for dike construction and marsh planting. Dike construction costs were determined by the GL, while marsh planting costs were estimated by the Environmental Laboratory.

Dike Construction Costs

145. The costs reported here for dike construction are the estimated costs for the recommended dike design at each of the potential dredged material disposal sites. These costs are based upon a dike crest elevation of +10 ft mlw at the Bowery Bay, Flushing Bay, and Raritan Bay sites and a crest elevation of +12 ft mlw at the Newark Bay site. Costs reflect a $10/lin ft cost for instrumentation but do not include the 30-percent contingency which is mentioned in Appendixes A-D.

Total costs

146. Since only one dike height and, therefore, only one dike design were considered by the GL for each disposal site, the total cost for dike construction at any particular disposal site is the same whether the site is developed for containment of contaminated material, for containment of uncontaminated material, or as a wetland. As shown in Table 7, the total cost for dike construction varies from a minimum of $3.1 million at Bowery Bay to a maximum of $18.4 million at Newark Bay. The total costs at Flushing Bay and Raritan Bay are, respectively, $8.2 million and $12.2 million. The cost at Bowery Bay is significantly less than the dike construction costs at the other

sites because dikes must be constructed along only one side of this site. Total cost at Newark Bay is much higher because of the combination of dike length and height required at this site.

147. The total cost for constructing dikes at the four proposed sites for containment of either uncontaminated or contaminated material is $41.9 million. To build the recommended dikes at the three proposed wetland sites would cost a total of $23.5 million.

Cost per lineal foot

148. The cost per linear foot of the dike constructed varies considerably. The lowest cost per lineal foot is $630 at Raritan Bay. This low cost results from use of the recommended floating dike design which requires much less fill material than does the recommended design at any other disposal site. The cost per linear foot is of the same order of magnitude at each of the other sites. These costs are $1,900/lin ft at Bowery Bay, $1,700/lin ft at Flushing Bay, and $2,100/lin ft at Newark Bay. The costs per lineal foot at these sites are similar because of the basically similar conditions at each site.

Cost per unit containment volume

149. The dike construction cost per cubic yard of storage volume created is often an effective way of determining the economic feasibility of constructing a containment/wetland creation area. In this analysis, the volume available inside each containment area is calculated by using the enclosed acreage of the disposal site and the dike height minus 2 ft of freeboard. The total cost for dike construction at each site was then divided by the storage volume available to yield a cost per cubic yard of volume available for storage at each site. These costs were $1.96/yd^3$ at Bowery Bay, $7.28/yd^3$ at Flushing Bay, $4.88/yd^3$ at Newark Bay, and $2.51/yd^3$ at Raritan Bay; the costs per cubic yard of containment volume are the same for both the contaminated and uncontaminated containment area scenarios.

150. For wetland creation, the volume available for storage of dredged material was considered to be that volume within the retaining dikes and below el +4 mlw. Utilizing these storage volumes, the cost per cubic yard of volume available for storage was calculated to be $2.67 for Bowery Bay, $10.51 for Flushing Bay, and $4.52 for Raritan Bay. This information is listed in Table 7.

Cost per unit volume of dredged material

151. The cost per cubic yard of contained dredged material was determined by dividing the total dike construction cost by the ultimate quantity of dredged material placed in the site. (Bin yardages were utilized in this analysis.) Since different quantities of dredged material were ultimately placed in the disposal sites for each of the three scenarios investigated; three different costs per unit volume were obtained for each site.

152. For containment area creation with uncontaminated sediments, the costs per cubic yard of contained dredged material varied from a minimum of \$1.08 at Raritan Bay to a maximum of \$5.94 at Flushing Bay. The costs at the other containment areas were \$1.55/yd^3 at Bowery Bay and \$3.83/yd^3 at Newark Bay. This results in an average cost per cubic yard of contained uncontaminated material of \$2.15.

153. Because disposal of contaminated material required analysis of both a best case and a worst case condition at three of the four sites, three of the proposed disposal sites have both best case and worst case prices. If the contaminated dredged material is not allowed to undergo evaporative drying (worst case), the cost per cubic yard of contained dredged material is \$1.83 at Bowery Bay, \$6.95 at Flushing Bay, \$4.53 at Newark Bay, and \$2.06 at Raritan Bay. The average cost per cubic yard for the worst case disposal of contaminated dredged material is \$3.30. If contaminated dredged material is allowed to desiccate, the best case per cubic yard of contained dredged material is \$0.87 at Bowery Bay, \$2.86 at Flushing Bay, and \$2.72 at Newark Bay; since the dredged material at Raritan Bay would not be subjected to evaporative drying, the cost per cubic yard of contained material would remain at \$2.06. The average cost per cubic yard for the best case disposal of contaminated dredged material is \$2.19.

154. Wetland creation results in costs per cubic yard of contained dredged material of \$1.35 at Bowery Bay, \$4.74 at Flushing Bay, and \$2.03 at Raritan Bay. The average cost per cubic yard for this analysis is \$2.34.

155. The variation in cost per cubic yard of contained material for the individual disposal sites is the result of differences in volume available for storage, initial lift thickness placed in the disposal site, and/or sediment compressibility characteristics, all of which affect the ultimate quantity of material placed in the disposal site.

Marsh Planting Costs

156. Costs for marsh planting will only be incurred for the three wetlands creation areas. Typical costs for planting smooth cordgrass (*S. alterniflora*) on 1-m centers in wetland areas in the New York Harbor region range from $4,000 to $6,000/acre. For this analysis, an average cost of $5,000 was used. This results in marsh planting of $0.33 million at Bowery Bay, $0.27 million at Flushing Bay, and $1.68 million at Raritan Bay. These costs include only obtaining, maintaining, planting, and replacing propagules of smooth cordgrass; they do not include dike building or dredged material placement.

Total Costs

157. The total cost for creation of containment areas would consist only of the cost of dike construction at each site. These costs, for containment of either contaminated dredged material or uncontaminated dredged material, were estimated to be $3.1 million at Bowery Bay, $8.2 million at Flushing Bay, $18.4 million at Newark Bay, and $12.2 million at Raritan Bay.

158. The total cost for creation of wetlands includes dike construction and marsh planting costs. For the three potential wetland creation sites, the total costs are $3.43 million at Bowery Bay, $8.47 million at Flushing Bay, and $13.88 million at Raritan Bay. The much higher cost at Raritan Bay results from enclosure of a larger area. This larger area requires a much greater length of dike to surround it and more marsh planting to cover the entire surface area.

PART VI: SUMMARY AND CONCLUSIONS

159. In the following paragraphs, a number of conclusions are drawn, and recommendations are made concerning the use of the four proposed disposal sites for containment area and wetland creation. When the disposal sites at Bowery Bay, Flushing Bay, Newark Bay, and Raritan Bay are utilized, application of the findings of this study to dredged material disposal and site management will result in placement of a maximum quantity of dredged material and development of an efficient and productive disposal site.

160. The information presented in this report should provide sufficient detail for development of preliminary plans for disposal of dredged material in the New York Harbor area. This information should provide a basis for selecting sites for further evaluation.

161. Based upon findings of this study, retaining dikes can be built on the existing foundation soils at the proposed disposal sites although some mud waves will likely form as a result of foundation soil displacement during dike construction. Before final dike designs are developed and dikes are constructed, comprehensive foundation soil samples should be taken, and both consolidation and strength tests should be run to determine the compressibility and shear strength of foundation soils at each site. These soil properties should then be used in appropriate settlement predictions and analyses of dike resistance to failure by the various modes mentioned in Part II. This approach would provide more reliable predictions of foundation soil behavior than were possible in this study.

162. The height of dikes needed for the various disposal options should be carefully considered. The dike crest elevations assumed for the designs described in the appendixes should be adequate for wetland creation although higher dikes should probably be used for all containment areas to reduce the possibility of overtopping by the waterbodies located outside the confining dikes. The dike crest elevation is especially critical when contaminated dredged material is to be placed in the containment areas. Dike heights should provide at least 2 ft of freeboard above the selected design storm surge.

163. Because initial lift thickness affects the ultimate quantity of dredged material which can be placed in a disposal site, it is preferable to place thin lifts of material in order to extend the service life of the site.

Therefore, from a site capacity perspective, the dredged material should be prorated to the disposal sites based upon either site surface area or volume. Prorating material to disposal sites would have a significant beneficial effect upon site capacity of both the containment area and wetland stabilization scenarios since for both of these disposal options, equal distribution of dredged material to each site was assumed regardless of the size of the site.

164. When dredged material is placed at a disposal site, the coarse-grained portion of the material will drop out of suspension at the discharge point and will tend to form mounds. Because of this fact, a decision must be made as to the type and variability of habitat desired for the wetland option. If only one type of habitat is desired, then mounds should not be allowed to form, or if formed, they should be leveled to create the appropriate elevation across the entire disposal site. On the other hand, if a varied habitat including both upland and wetland areas is desired, the mounds may be allowed to form and remain.

165. Two of the proposed disposal sites are located adjacent to the La Guardia Airport. When these sites in Bowery Bay and Flushing Bay are developed, consideration must be given to the type of surface/habitat created and its attraction for birds since birds pose a severe hazard to air traffic. Therefore, these sites should be managed to minimize bird usage. Selection and development of appropriate habitat can effectively minimize bird usage of the disposal sites and any resultant aviation hazard. This can be done through careful selection of final site elevation and allowable vegetation types.

166. In determining the optimum use of each proposed disposal site, consideration must be given to the quantities of dredged material to be disposed, the availability of alternative disposal sites/options, and the cost of site creation and dredged material disposal. If large quantities of material must be disposed, then it is recommended that the four sites be used as containment areas, not wetlands, since more material can then be placed in each site. Additionally, the dredged material should be allowed to undergo evaporative drying to further increase the quantity of material which can be placed at each site. If it is necessary to mitigate detrimental effects of other dredging work, then wetland stabilization would be desirable. The costs of each of the three disposal scenarios (containment area-uncontaminated, containment area-contaminated, and wetland) investigated in this report should be

compared and considered in light of budget constraints. The optimal use of these sites can then be determined and can be compared to other disposal options in order to determine the feasibility of constructing these facilities.

167. If the four sites analyzed in this report are to be used for disposal of contaminated sediments, additional laboratory testing and data analysis must be performed to assess the level of contamination in the sediments and possible site controls needed to contain the contaminants within the sites. Such analyses are beyond the scope of this project. Therefore, this report did not consider nor evaluate the control measures necessary to handle contaminated sediments; neither technical descriptions nor costs were addressed. These factors should be considered in future studies which must be conducted before implementation of disposal of contaminated dredged material.

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Table 1

Storm-Surge Elevations for Bowery Bay

Return Interval years	Maximum Surge Elevations ft, mlw
1	9
3	10
8	11
30	12
100	13

Table 2

Storm-Surge Elevations for Flushing Bay

Return Interval years	Maximum Surge Elevations ft, mlw
1	9
3	10
8	11
30	12
100	13

Table 3

Storm-Surge Elevations for Newark Bay

Return Interval years	Maximum Surge Elevations ft, mlw
1	7
3	8
8	9
30	10
100	11

Table 4

Storm-Surge Elevations for Raritan Bay

Return Interval years	Maximum Surge Elevations ft, mlw
1	9
3	10
8	11
30	12
100	13

Table 5

Average Monthly Climatological Data for New York Harbor Area

Month	Rainfall in.	Pan Evaporation in.
January	3.31	0.00
February	3.02	0.00
March	3.94	0.00
April	3.58	1.92
May	3.51	4.80
June	3.42	4.92
July	3.77	5.88
August	4.23	3.84
September	3.63	4.68
October	3.07	1.92
November	3.53	0.00
December	3.45	0.00

Table 6

Sediments to be Deposited in Various Containment Areas

Containment Area	Diked Surface Area acres	Sediment	Annual Quantity yd^3	Annual Lift Thickness ft
		Uncontaminated Scenario		
Bowery Bay	65	A	1,133,000	17.0
Flushing Bay	54	A	1,104,000	20.2
Newark Bay	156	B	1,375,000	10.7
Raritan Bay	335	C	565,000	1.8
		Contaminated Scenario		
Bowery Bay	65	D	169,000	3.2
Flushing Bay	54	D	169,000	3.8
Newark Bay	156	D	169,000	1.4
Raritan Bay	335	D	169,000	0.6

Table 7

Dike Construction and Marsh Planting Costs

Disposal Site	Dike Construction Costs: Total Cost for Dike Construction $	Dike Construction Costs: Cost/Ft of Dike $/lin ft	Dike Construction Costs: Cost/Vol of Volume Available for Storage $/$yd^3$	Dike Construction Costs: Cost/Vol of Contained Dredged Material $/$yd^3$	Marsh Planting Costs: Cost/Area $/$yd^2$	Marsh Planting Costs: Total Cost $	Total Cost $
Containment Area (Uncontaminated)							
Bowery Bay	3.1 M	1,900	1.96	1.56	--	--	3.1 M
Flushing Bay	8.2 M	1,700	7.28	5.90	--	--	8.2 M
Newark Bay	18.4 M	2,100	4.88	3.81	--	--	18.4 M
Raritan Bay	12.2 M	630	2.51	1.07	--	--	12.2 M
Containment Area (Contaminated)							
Bowery Bay	3.1 M	1,900	1.96	0.87-1.83	--	--	3.1 M
Flushing Bay	8.2 M	1,700	7.28	2.86-6.95	--	--	8.2 M
Newark Bay	18.4 M	2,100	4.88	2.72-4.53	--	--	18.4 M
Raritan Bay	12.2 M	630	2.51	2.06	--	--	12.2 M
Wetland Creation							
Bowery Bay	3.1 M	1,900	2.67	1.49	1.03	0.33 M	3.43 M
Flushing Bay	8.2 M	1,700	10.51	4.90	1.03	0.27 M	8.47 M
Raritan Bay	12.2 M	630	4.52	2.32	1.03	1.68	13.88 M

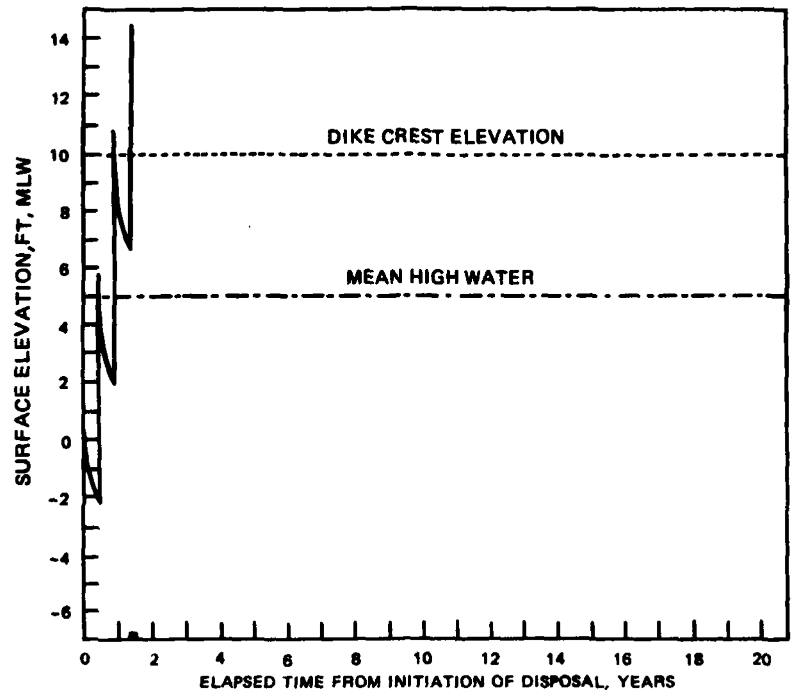


Figure 1. Filling simulation for upland disposal of uncontaminated dredged material at Bowery Bay, New York

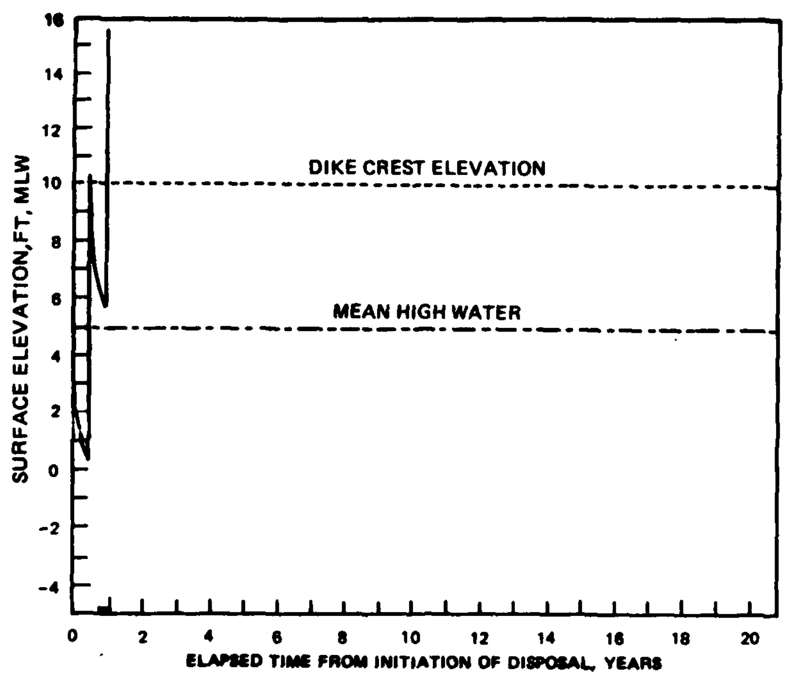


Figure 2. Filling simulation for upland disposal of uncontaminated dredged material at Flushing Bay, New York

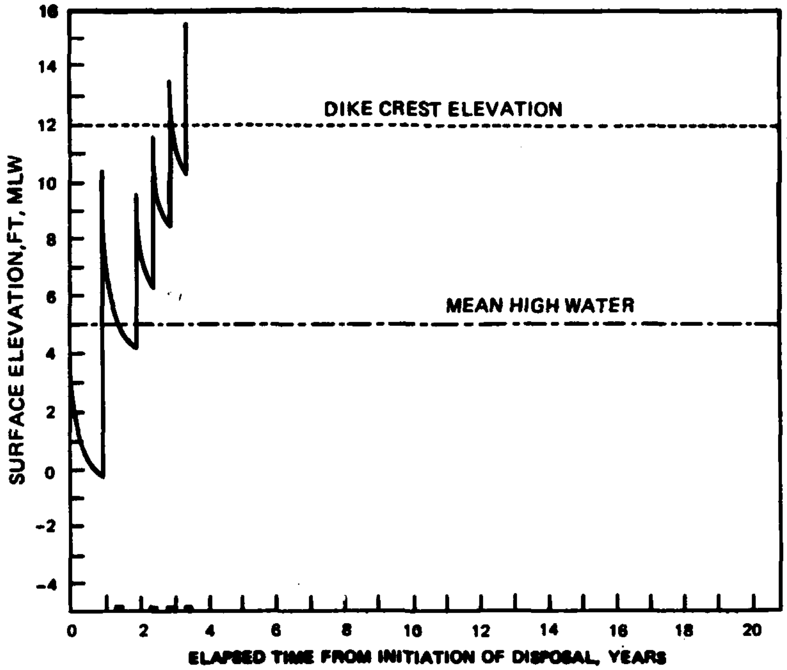


Figure 3. Filling simulation for upland disposal of uncontaminated dredged material at Newark Bay, New Jersey

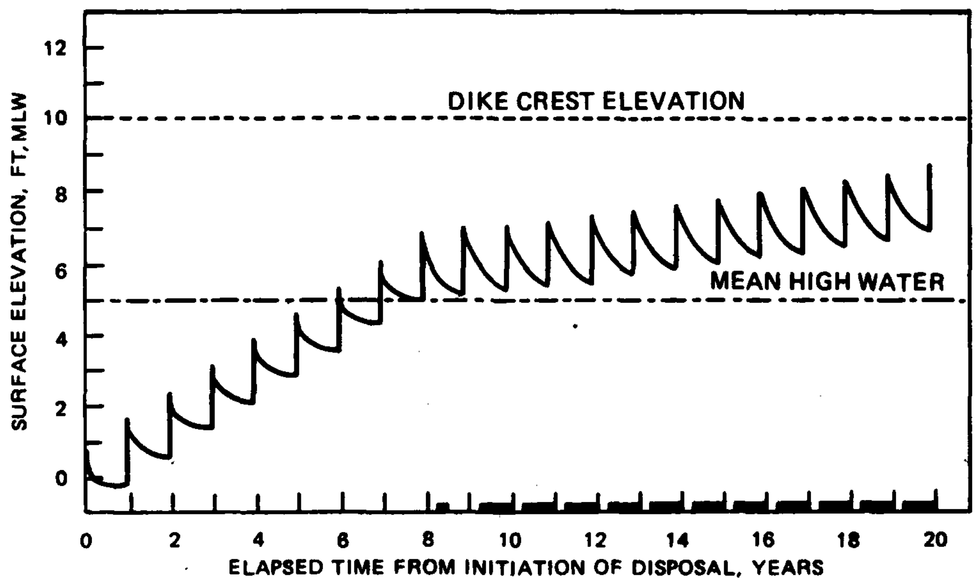
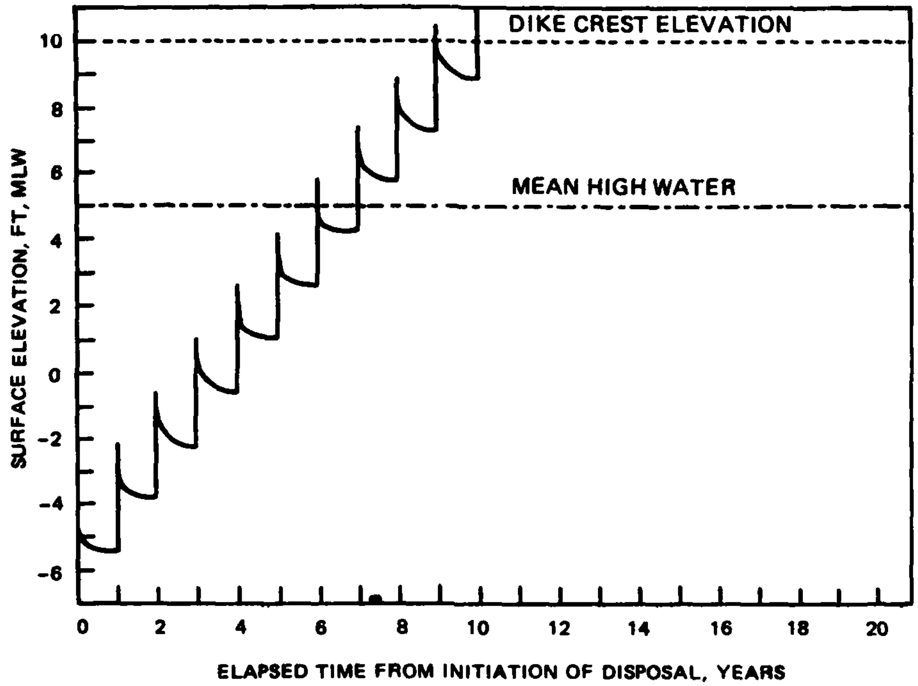
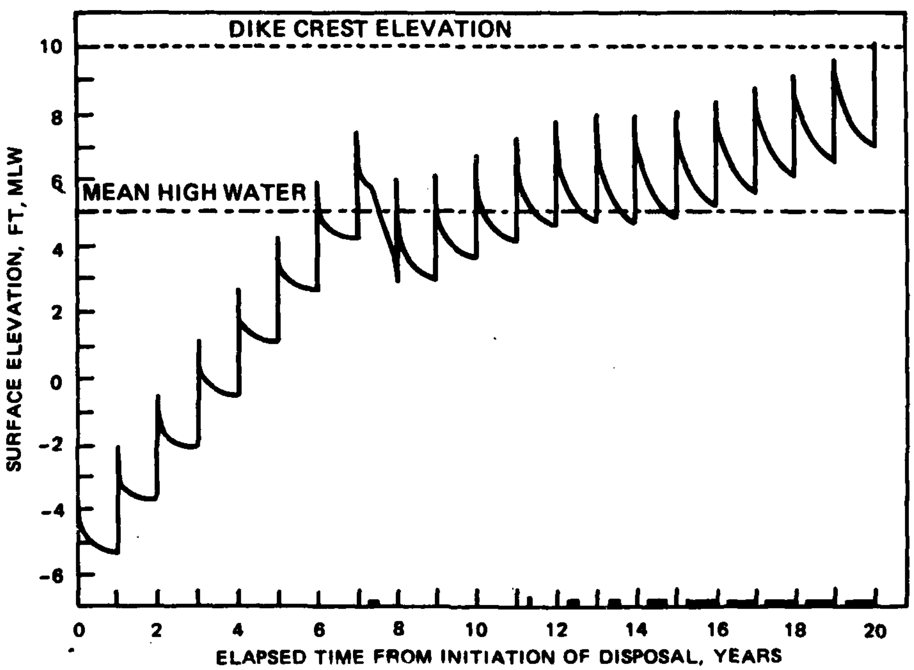


Figure 4. Filling simulation for upland disposal of uncontaminated dredged material at Raritan Bay, New Jersey

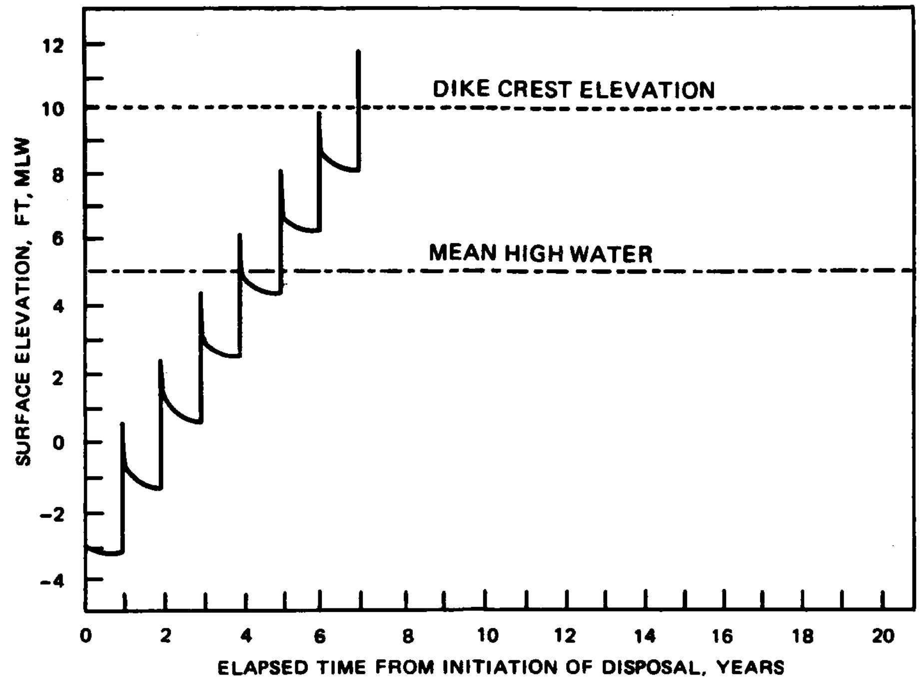


a. Worst case

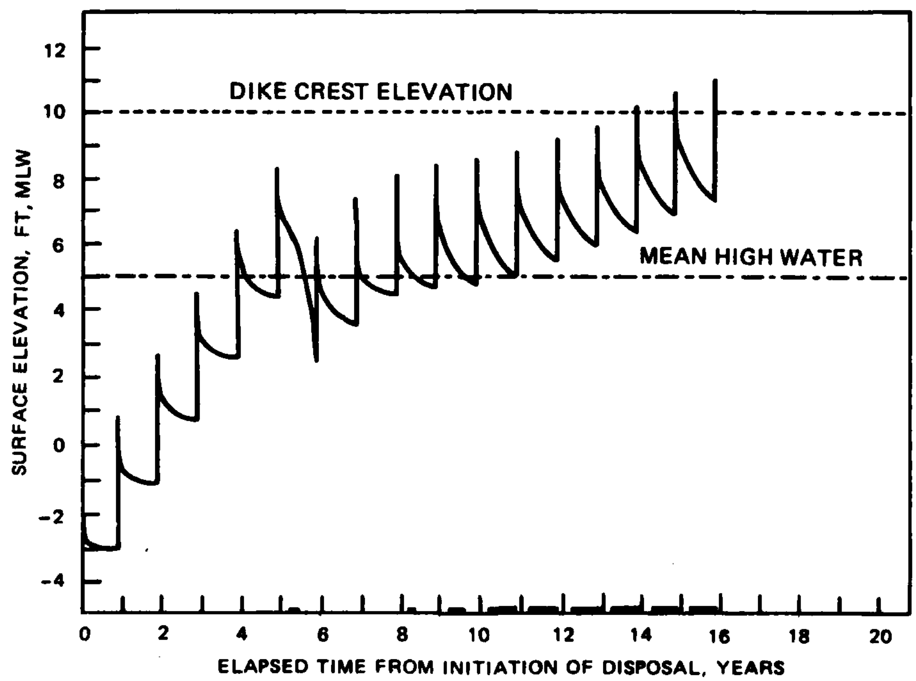


b. Best case

Figure 5. Filling simulation for upland disposal of uncontaminated dredged material at Bowery Bay, New York

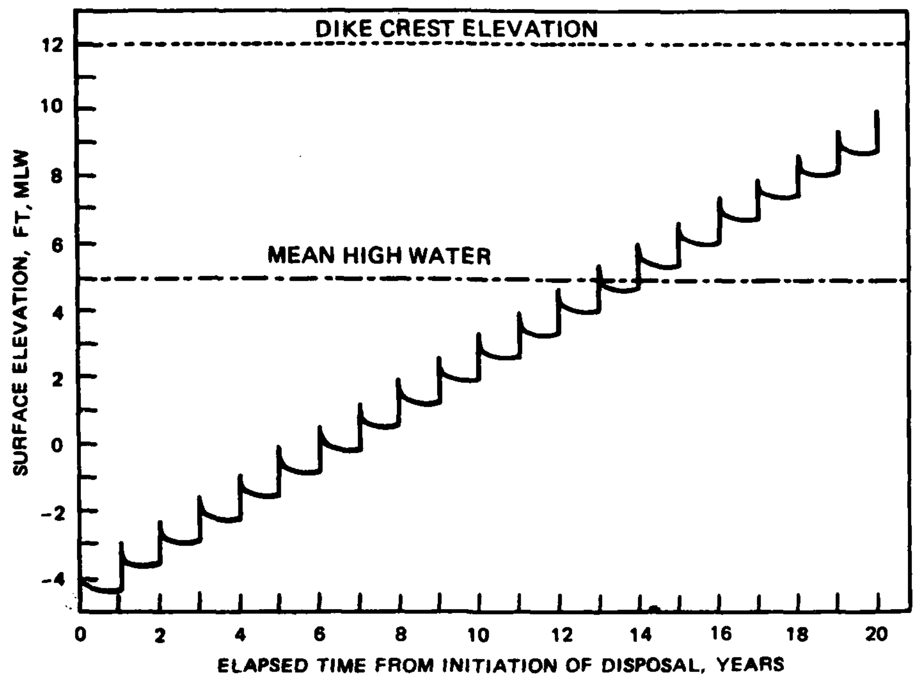


a. Worst case

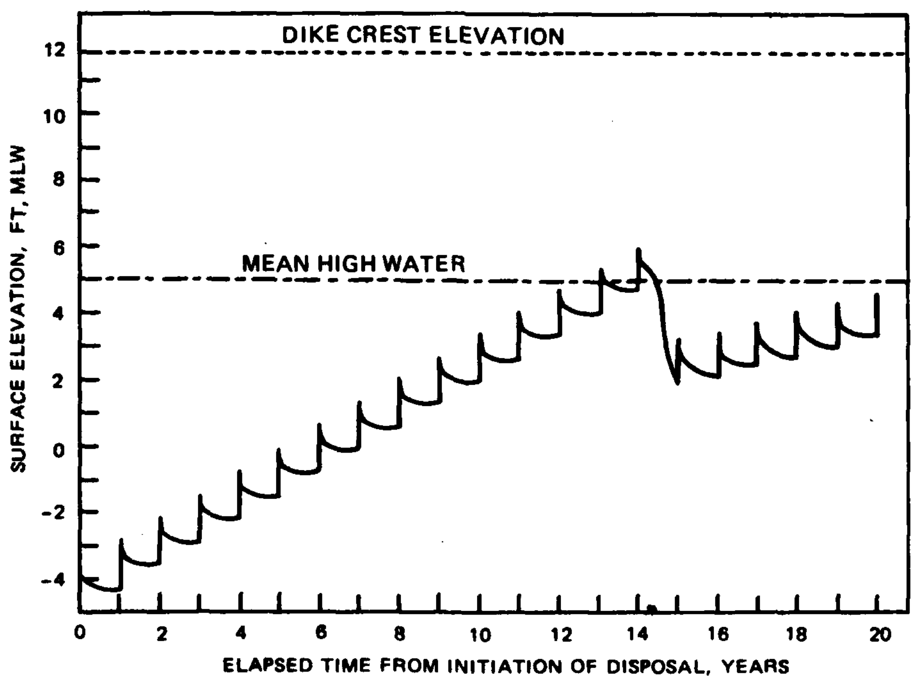


b. Best case

Figure 6. Filling simulation for upland disposal of contaminated dredged material at Flushing Bay, New York



a. Worst case



b. Best case

Figure 7. Filling simulation for upland disposal of contaminated dredged material at Newark Bay, New Jersey

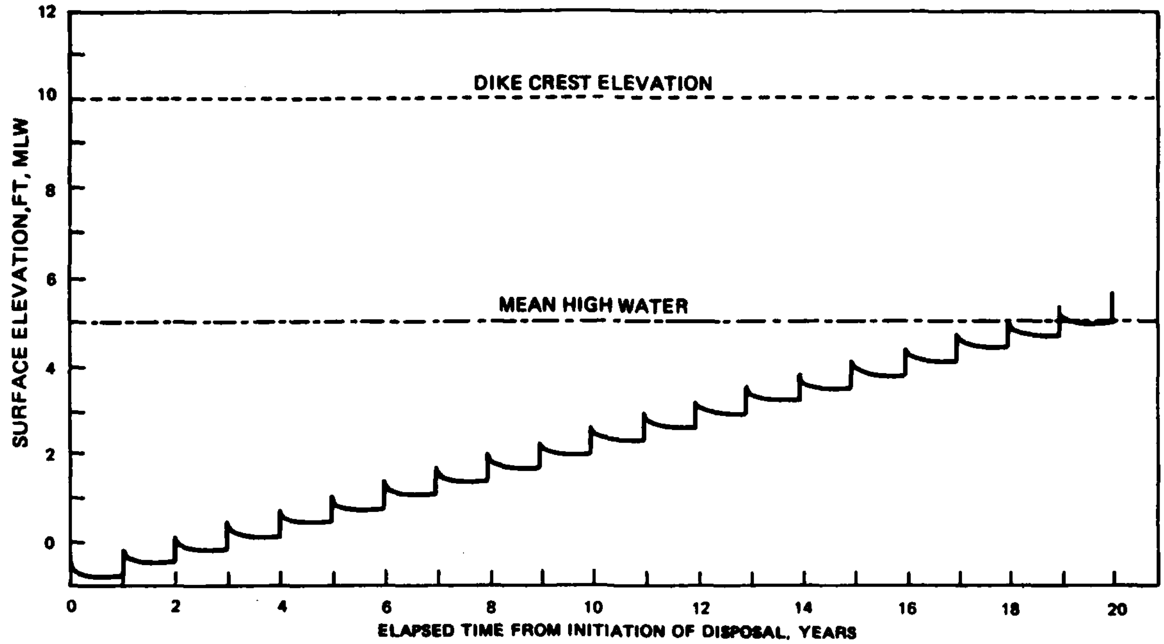


Figure 8. Filling simulation for upland disposal of contaminated dredged material at Raritan Bay, New Jersey

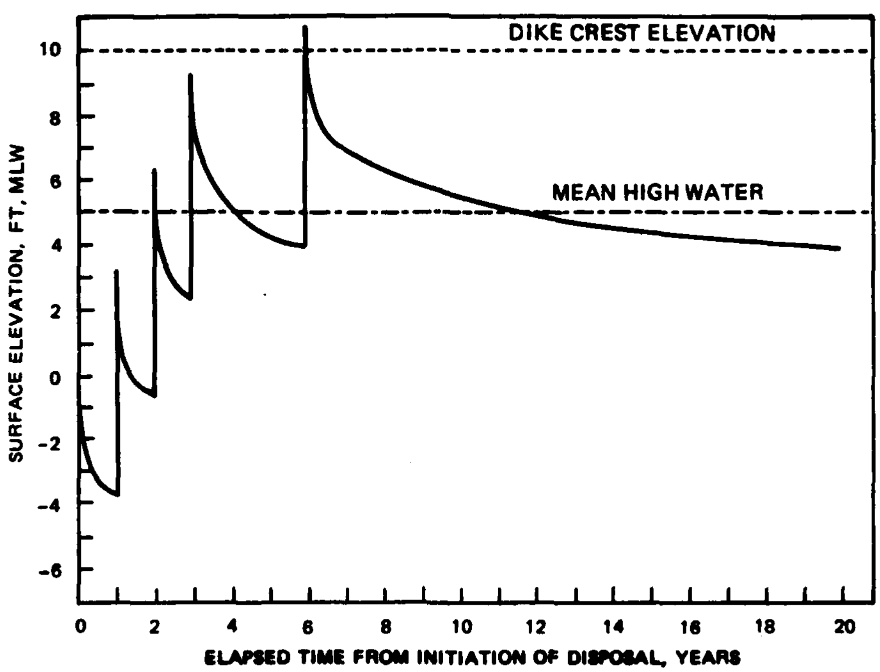


Figure 9. Filling simulation for wetland creation with uncontaminated dredged material at Bowery Bay, New York

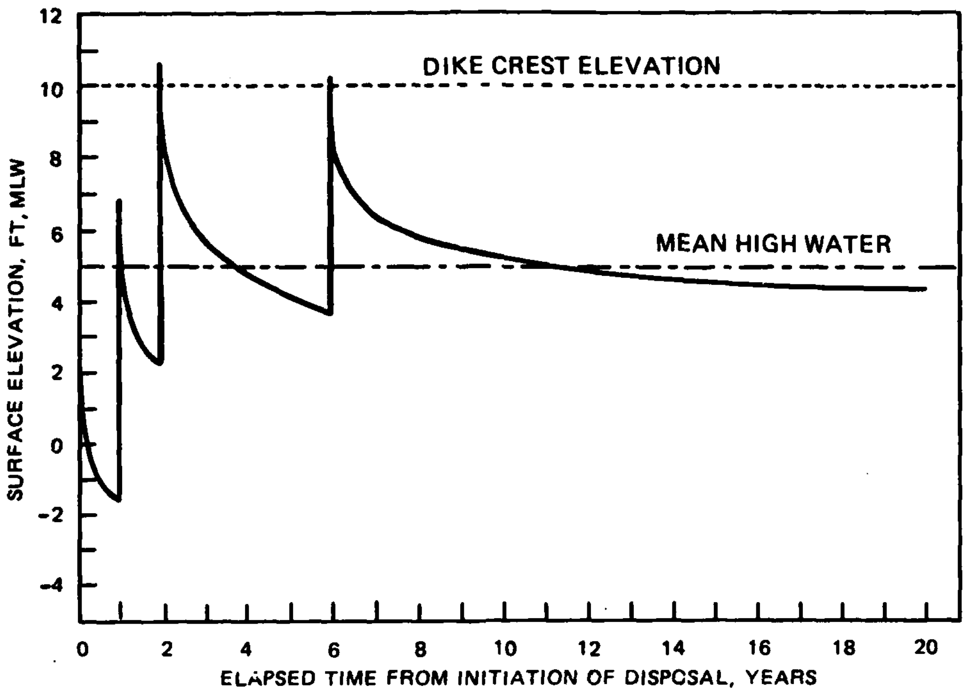


Figure 10. Filling simulation for wetland creation with uncontaminated dredged material at Flushing Bay, New York

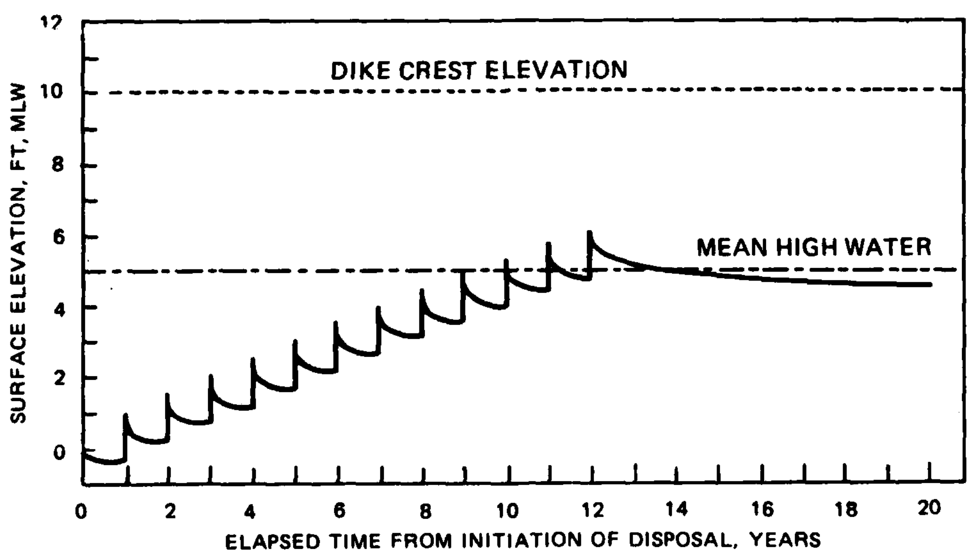


Figure 11. Filling simulation for wetland creation with uncontaminated dredged material at Raritan Bay, New Jersey

APPENDIX A: GEOTECHNICAL REPORT FOR BOWERY BAY, NEW YORK

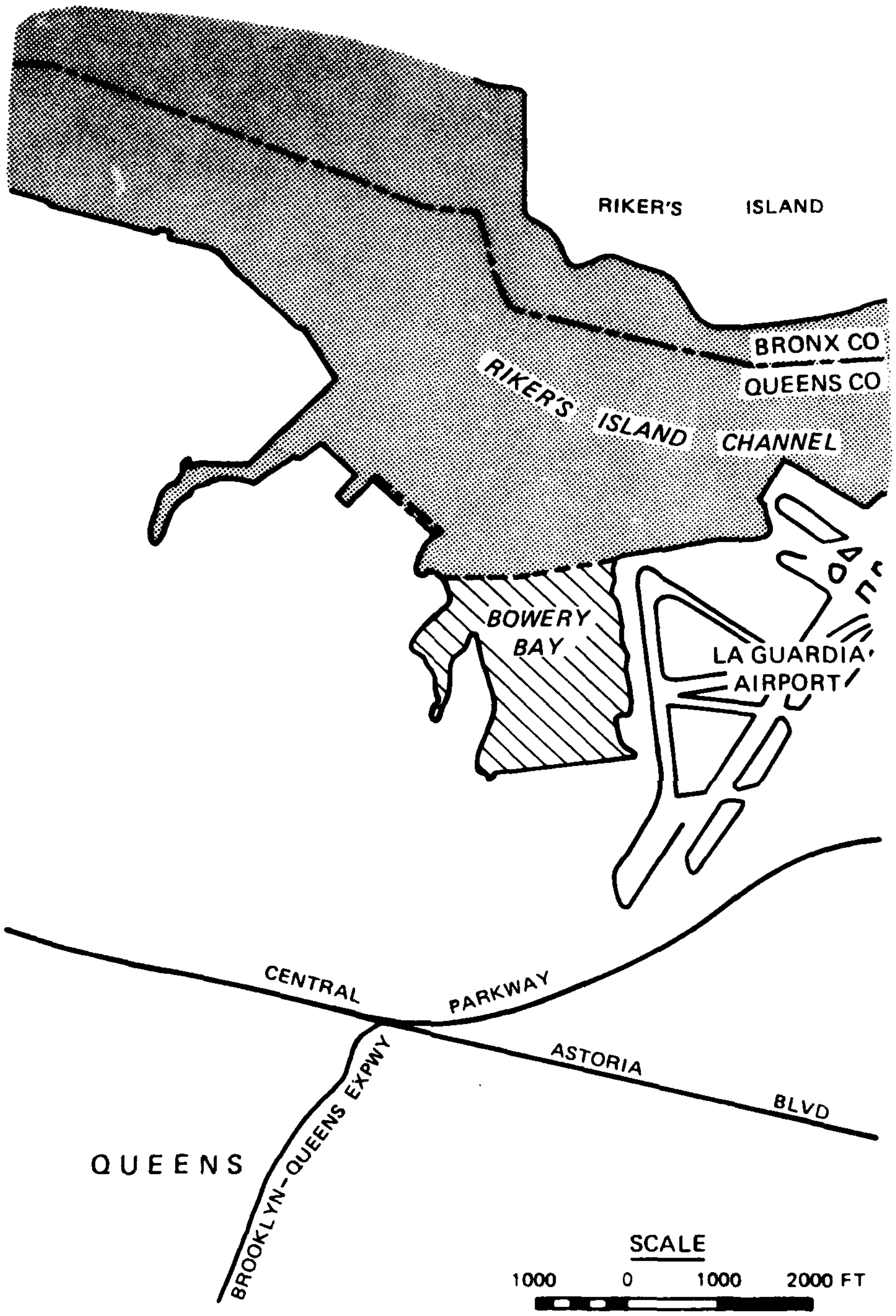
Introduction

1. As part of the engineering and economic feasibility study for the development of dredged material containment areas in New York Harbor, preliminary geotechnical analysis and evaluation of the potential sites were performed. The potential containment area at Bowery Bay examined in this study has been identified as such by the New York District (NYD) and the Port Authority of New York and New Jersey (PANYNJ). The purpose of this study is to describe the probable subsurface conditions existing at this site and provide information on the feasible design and construction scenarios for the containment dikes. An estimate of the construction sequence has been provided. This study is based on limited subsurface data provided by the NYD and the PANYNJ, but the subsurface soil profiles and design parameters used in this study are believed reasonable.

Site Description

2. The dredged material containment area proposed for Bowery Bay is outlined in Figure A1. The proposed containment site is to be bound by Riker's ship channel on the north, La Guardia Airport on the east, and the areas of North Beach and Steinway on the south and west, respectively. Initially the proposed disposal site encompassed approximately 75 acres which is represented by Areas A and B on Figures A1 and A2; however, the use of Area B is not believed to be economically feasible.

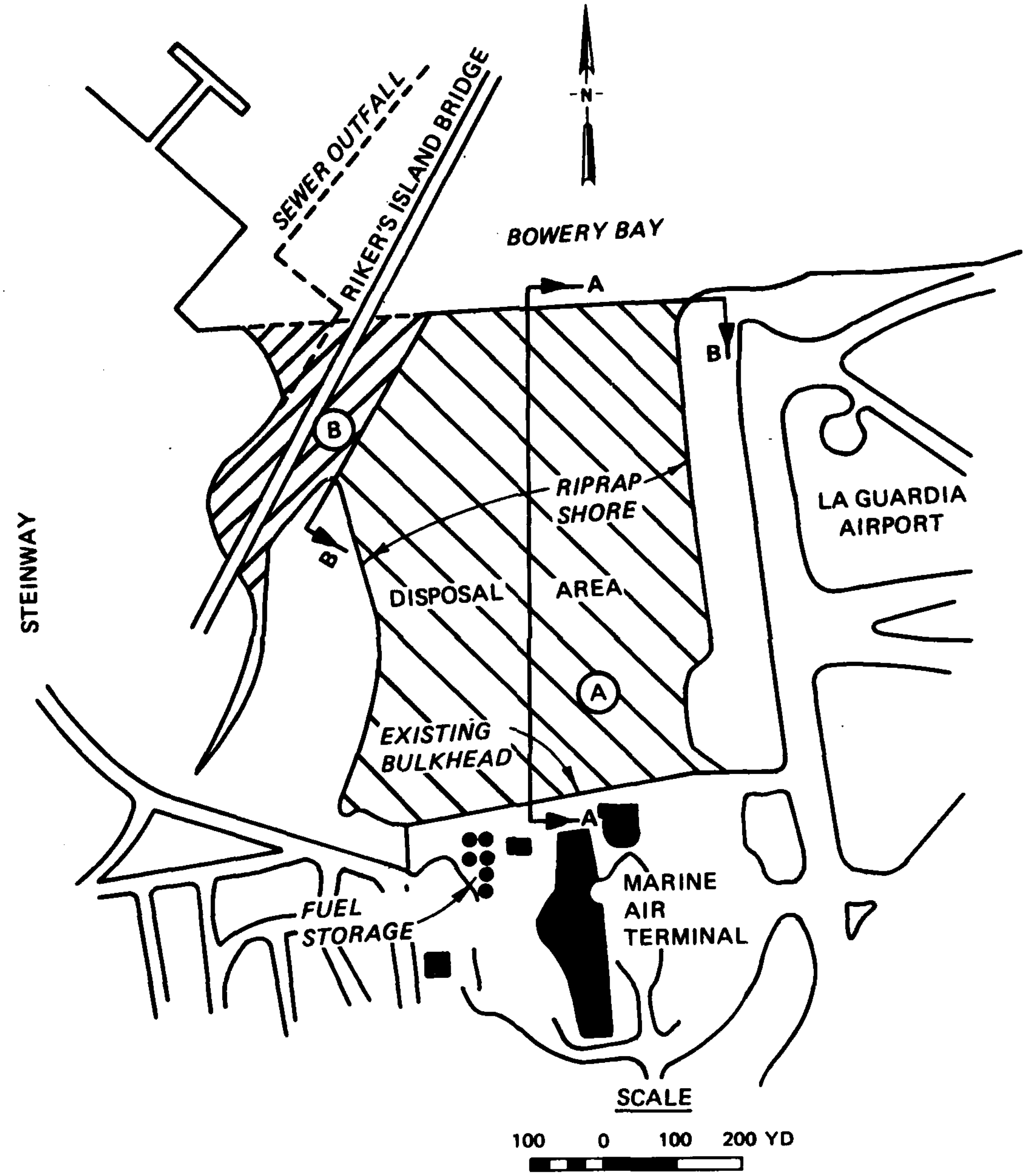
3. There are two primary features which eliminate Area B as a potential low cost disposal area. One feature is the presence of a sewer line (outfall) within the limits of the site and would require the relocation of the sewer line prior to use of the site as a disposal area. The second feature is the presence of the exposed bridge piers used to support the Riker's Island Bridge. If this site is to be used as a containment area, then the piers must be protected from the development of negative skin friction (down drag) as the soft dredged material consolidates. There are several design options available to eliminate or significantly reduce this potential load on the bridge piers. The most feasible option consists of isolating the bridge piers from the dredged material. In addition to the negative skin friction, the weight of the dredged material and retaining dikes could cause sufficient



NOTE: 1. DISPOSAL AREAS A AND B WERE PROPOSED PRIOR TO THIS STUDY.

2. BECAUSE OF THE HIGH COSTS ASSOCIATED WITH RELOCATING EXISTING FACILITIES, DISPOSAL AREA B IS NOT RECOMMENDED.

Figure A1. Location of proposed disposal area in Bowery Bay, New York



NOTE: 1. PROFILE SECTION LINE B--B TAKEN ALONG OUTER TOE OF PROPOSED DIKE.
2. DISPOSAL AREA B IS NOT INCLUDED IN THIS STUDY.

Figure A2. Location of soil profile section lines in Bowery Bay disposal area

consolidation of the underlying soils to affect alignment of the bridge.

4. From an engineering viewpoint, it would be possible to relocate and/or modify the existing facilities to develop site B into a usable disposal area. The cost to make the necessary changes would be from $13 million to $20 million, not including dike construction. From a practical viewpoint, the investment of such a large amount of money and resources for a site that is only about 10 acres in size with an average bottom elevation of -1 ft mlw is not recommended; therefore, the construction scenarios and costs presented in this report are based on using Disposal Area A only.

5. Disposal Area A is about 2,000 ft long and 1,450 ft wide and encompasses approximately 67 acres including the dikes. The elevation of the bottom varies from 0 to -18 ft mlw with an average elevation of -7 ft mlw. The elevation of the surrounding land is +10 ft mlw with small perimeter dikes constructed to el +15 mlw on the east (La Guardia Airport), +12 ft mlw at the marine air terminal on the south, and +14 ft mlw to the west.

6. The bottom of the site is composed of approximately 6 ft of very soft organic silt extending from an average elevation of -7 to -13 ft mlw. This very soft material is underlain by about 14 ft of soft organic silt extending from approximately el -13 to -27 ft mlw. Below the soft silt is about 16 ft of medium dense silty sand extending from an average elevation of -27 to -41 ft mlw. Underlying the silty sand is another layer of silt. A review of boring logs made in areas adjacent to the proposed site indicates this silt layer to be only a few feet thick and underlain by a dense silty gravelly sand extending to an undetermined depth. A profile believed to be representative of the subsurface soils through the center of the containment area and along the center line of the required dike is shown in Figures A3 and A4.

7. A condition which must be considered in the overall site evaluation is the relocation and/or construction of support facilities for the fuel storage tanks at the south end of the proposed site. It is believed the fuel storage tanks are refilled by the use of barges which require that a minimum water depth be maintained in Bowery Bay. This belief is supported by the relatively uniform water depth in the center of the site as shown in Figure A3. It is unlikely that sufficient flushing of this area is occurring, particularly at the south end, to prevent shoaling; therefore, this area has probably been dredged. The estimate of any relocation or construction costs

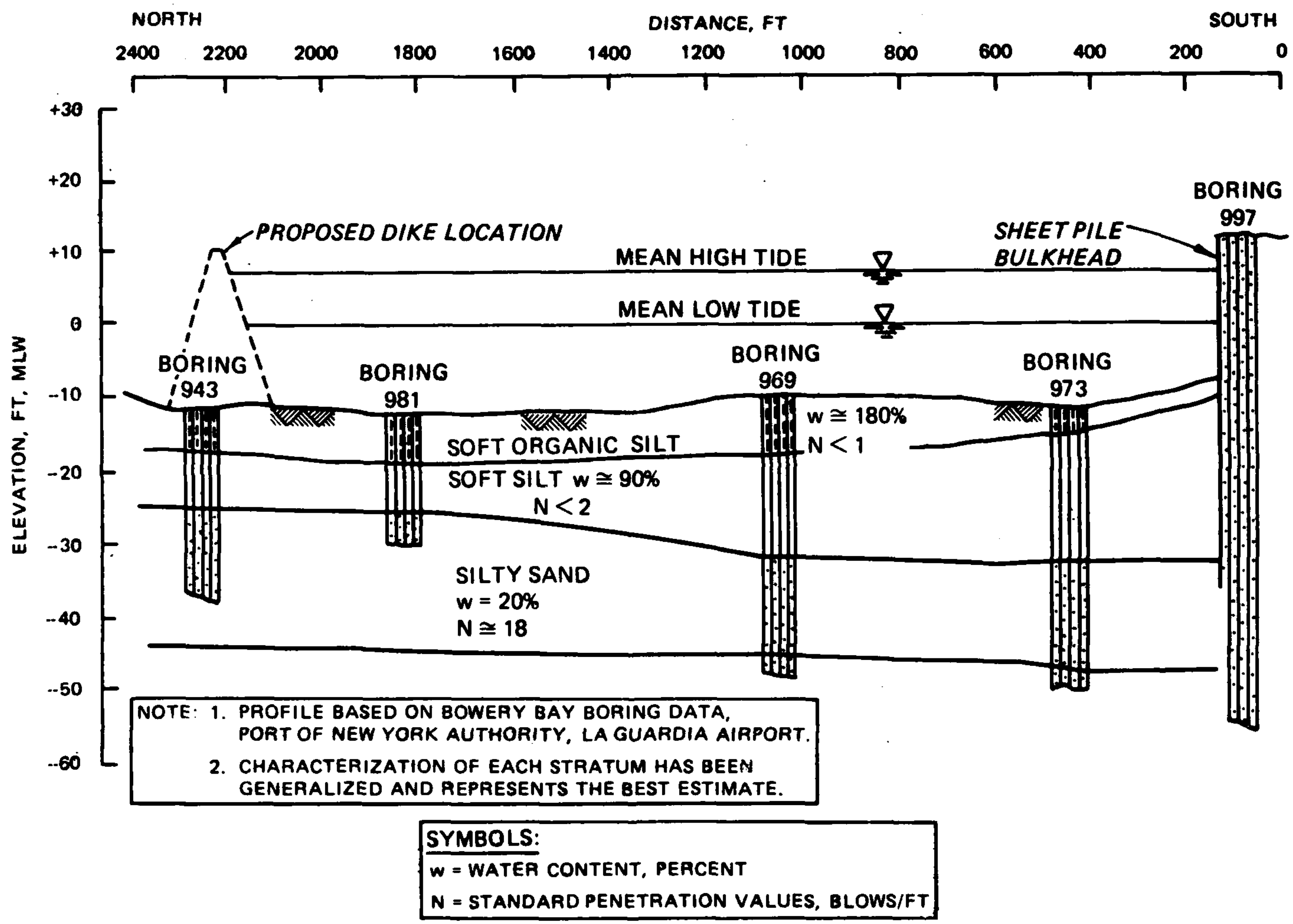


Figure A3. Soil profile A-A through center of proposed containment area

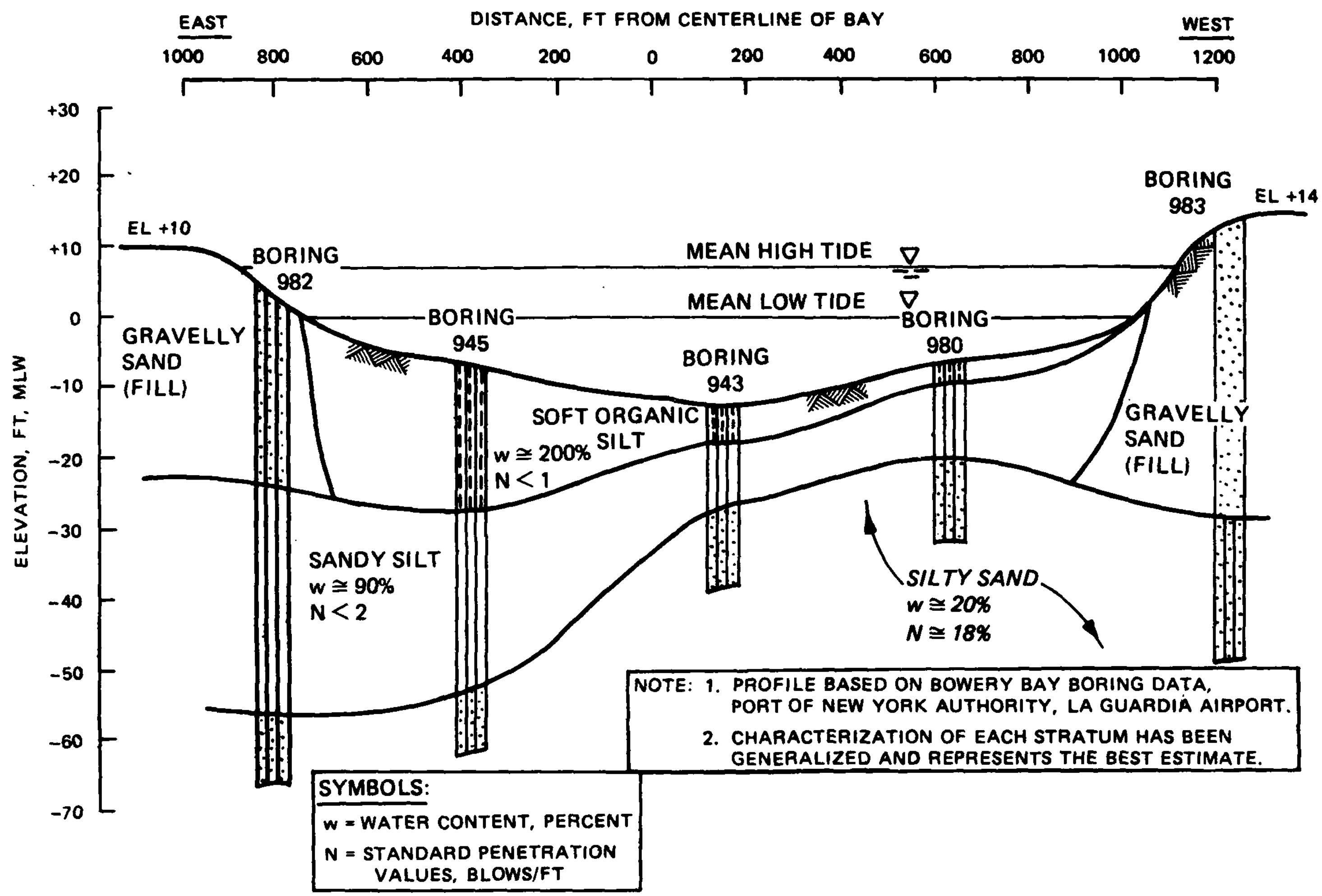


Figure A4. Soil profile B-B along proposed dike center line

to the local businesses as a result of using the lower reaches of Bowery Bay as a containment area is beyond the scope of this study.

General Design Considerations

8. An important consideration in the evaluation of this site is the limited length of containment dike which would have to be constructed. Since on the east, south, and most of the west side of the site, previous construction has raised the perimeter elevations to at least +12 ft mlw, no additional raising of these surfaces would be necessary; therefore, the construction of only about 1,700 ft of containment dike would be necessary on the north and northwest sides as shown in Figure A2. Logs of borings made in the area were provided by PANYNJ.

9. As shown in Figure A4, a major consideration in the construction of the containment dikes is the soft foundation soils. These soft soils consist of very soft organic silt underlain by a soft sandy silt. The organic silt varies in thickness from about 2 ft on the northwest side of the site to approximately 22 ft on the northeast side. The water contents vary from over 250 percent to less than 50 percent with an average of about 200 percent. The results of limited standard penetration test (SPT) data and soil descriptions indicate an average SPT value of 1. Based on a relationship between SPT values, corrected for depth as outlined by Peck, Hanson, and Thornburn (1974),* and soil strength developed by Hough (1969), the average shear strength (cohesion) for this soil would be about 50 psf.

10. Underlying the soft organic silt is a soft sandy silt which varies from 10 to 29 ft in thickness. The water contents of this material vary from less than 50 percent to over 150 percent with an average of about 90 percent. The results of limited SPT and soil descriptions indicate an average SPT value of about 2. Based on the relationships previously mentioned, an SPT value of 2 for this material corresponds to a shear strength (cohesion) of approximately 100 psf. Underlying this material is a silty sand extending to an undetermined depth. The water contents of the silty sand vary from about 12 to 40 percent with an average of 20 percent. The average SPT value determined

* References cited in this appendix are included in the References at the end of the main text.

from testing is about 18. This value corresponds to a friction angle of at least 32 deg assuming insignificant cohesion.

11. An assumed average soil profile for the soils beneath the proposed dike is shown in Figure A5. Also shown in Figure A5 are other soil values necessary for the development and analysis of the design scenarios. All soil parameters shown in Figure A5 are consistent with both experience in working with similar soils and available boring logs.

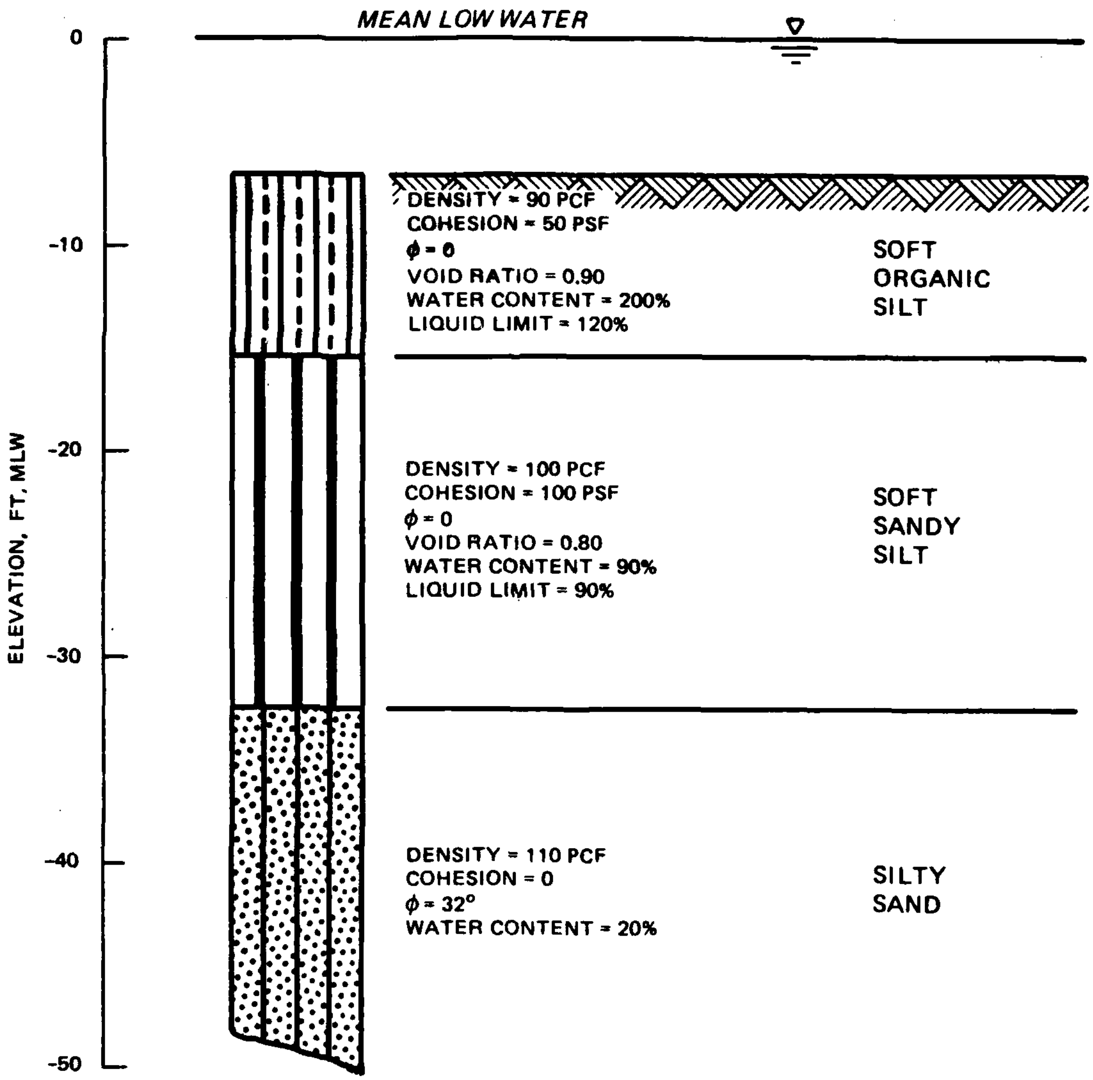
12. The design of the containment dikes must consider several possible modes of failure: (a) overtopping and/or erosion of the dike materials by storm surges, high tides, and wakes caused by shipping; (b) bearing failure of the soft foundation soils either during or immediately after construction; (c) slope failure caused by either rotating or sliding of a portion of the dike along the soft foundation soils; and (d) settlements which could result in the storage capacity being significantly reduced or cause serious distress within the dike.

13. An important consideration in the design of the dikes is the material which will be retained and/or the ultimate use of the site. If the site is to be used to contain contaminated dredged material then the dikes should be of sufficient height that overtopping and subsequent flushing of the containment area will not occur. A design dike height for the containment of contaminated dredged material should include a minimum of 2 ft of freeboard above the design storm surge elevation. The storm surge elevations with corresponding frequencies are shown in Table A1; this data was provided by the

Table A1

Storm-Surge Frequencies

Frequency years	Maximum Surge Elevations ft, mlw
1	9
3	10
8	11
30	12
100	13



NOTE: SOIL PROFILE AND DESIGN PARAMETERS ARE BASED ON AVAILABLE DATA.

DESIGN PARAMETERS ARE BELIEVED REASONABLE (THEY MAY BE CONSERVATIVE).

Figure A5. Assumed soil profile and design parameters

NYD. If the disposal area is to be used in the creation of wetlands, no freeboard need be included in the design since any damage to the dikes from an occasional overtopping could be repaired at a cost less than constructing the dikes initially to a height that would prevent overtopping. In the creation of wetlands, retaining dikes are temporary structures, and their cost should be minimized.

14. The ultimate bearing capacity of the soft foundation soils is approximately 275 and 800 psf of the organic silt and sandy silt, respectively. These values were determined using the equation recommended by Hammer and Blackburn (1977). A bearing strength of only 275 psf for the organic silt means a bearing failure will occur if a dike is constructed to an elevation of -1.5 ft mlw or greater. Although the underlying sandy silt has a shear strength of 100 psf, little additional bearing strength is gained. Based on an ultimate bearing capacity of 800 psf (including the effect of the overlying organic silt), a dike could only be constructed to el 0 before failure of this stratum would occur. Since neither the organic silt nor the sandy silt strata are capable of supporting the necessary dike height, failure of these soils in bearing is highly probable. A bearing failure will likely result in the formation of a mud wave caused by the lateral displacement of the soft soils. Construction procedures may need to be implemented to remove some of the displaced soils, thereby reducing the potential negative impact of the mud wave on the surrounding marine environment.

Design and Construction Scenarios

Displacement dike

15. Construction of retention dikes on soft soils consists of several basic methods with the displacement form of construction being the most common. This construction method allows the subsurface soils to become overstressed and to fail as a result of the imposed dike load. The failure consists of the lateral displacement of large volumes of weak foundation soils. Displacement of the weak soils continues until sufficient fill material has replaced these weaker soils to provide adequate bearing to support the dikes. The volume of soil which is likely to be displaced is dependent upon a number of factors, but it is not uncommon for the final displaced volume to be six to eight times the design dike volume.

16. The relatively high dikes required and the correspondingly large bearing stresses will cause most of the soft organic silt and sandy silt to be displaced during construction. The only economical way to construct a displacement dike at this site is by the use of relatively low cost locally dredged sands. It is believed that 370 yd^3/lin ft of fill will be required to construct the dikes to a crest elevation of +10 ft mlw. The minimum crest width should be 10 ft with side slopes not steeper than 1V:6H. The estimated volume of 370 yd^3/lin ft of dike includes the volume of fill necessary to compensate for settlement and compression of the dike and foundation soils.

17. It is recommended that the outboard side of the dike be protected from wave and tidal degradation by using a 2-ft layer of rock underlain by a soil and fabric filter. The rock should weigh from 130 to 180 lb each and be uniformly placed in a minimum of 2 lifts. The slope protection system should extend the full length of the slope.

18. The estimated construction volumes and costs, based on unit costs provided by NYD and presented in Table A2, are shown in Figure A6. The

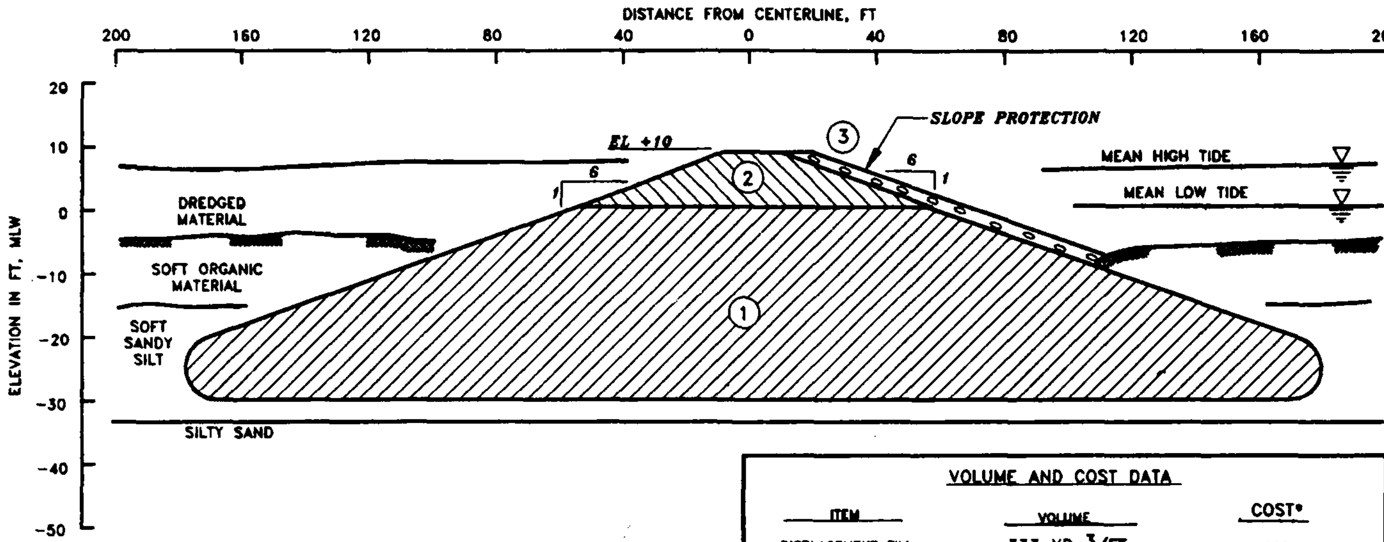
Table A2

Estimated Construction Unit Costs*

Construction element	Unit Cost $
Dredged sand (dumped)	6.00/yd^3
Dredged sand (dumped, shaped, and densified)	7.50/yd^3
Rock (slope protection)	30.00/yd^3
Soil and fabric filter (slope protection)**	16.00/yd^2
Filter fabric (reinforcement)	4.00/yd^2

* Costs include transportation and placement.
** Cost based on filter thickness of 2 ft.

estimated cost for this design scenario is approximately $2,800/lin ft of dike constructed to el +10 ft mlw. The total dike construction costs will be about $4.6 million without any contingency and $6 million with a 30-percent contingency. Included in the estimated construction costs is $10/lin ft of dike for instrumentation. Instrumentation is necessary for the monitoring of settlements and the changes in pore pressures during and after construction.



CONSTRUCTION SEQUENCE

(1) PLACE AND SHAPE FILL TO CONSTRUCT A WORKING PLATFORM AT 0

(2) PLACE, SHAPE, AND COMPACT FILL TO 10

(3) PLACE FILTER FABRIC AND ROCK PROTECTION

VOLUME AND COST DATA

ITEM	VOLUME	COST*
DISPLACEMENT FILL	333 YD ^{3}/FT	1998
DENSIFIED DIKE FILL	37 YD ^{3}/FT	278
EROSION PROTECTION		
ROCK**	8 YD ^{3}/FT	240
FILTER	12 YD ^{2}/FT	192
INSTRUMENTATION		10
SUBTOTAL		2718
CONTINGENCY, (30%)		816
TOTAL		3534

*COST INCLUDES PLACEMENT

**COST BASED ON REUSING EXISTING SLOPE PROTECTION

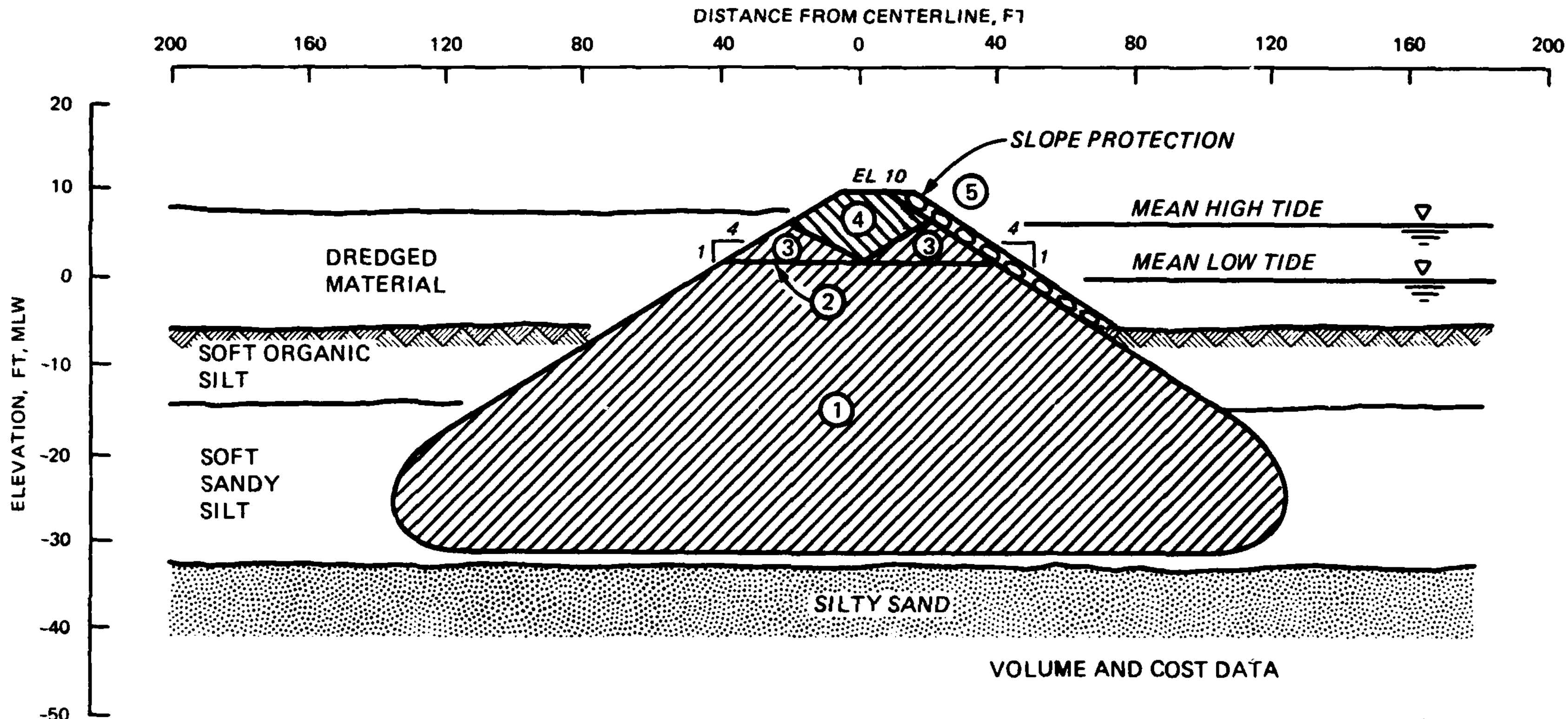
Figure A6. Displacement scenario for dike construction

Fabric strengthened dike

19. The concept of strengthening a dike by the use of reinforcement, such as a filter fabric, is relatively new. The primary advantage of using a fabric strengthened embankment is the ability to use slopes as steep as 1V:4H resulting in a significant savings in construction costs. A fabric-strengthened dike is similar to a floating dike where the lateral strains which occur within the embankment, both during and after construction, are controlled by the use of a reinforcing material. The reinforcing fabric must have both a high elastic modulus and a high ultimate strength to withstand the large tensile stresses likely to develop within the embankment. In addition to withstanding the tensile stresses, a good reinforcing material must maximize the frictional forces developed at the soil-fabric interface. If the fabric-strengthened dike is properly designed and constructed, a failure within the reinforced section will not occur. Therefore, slopes which would be too steep for a conventional dike can be safely used with a fabric strengthened dike.

20. Since the average elevation of the surface of the foundation is -7 ft mlw and the bearing strength of the soft organic silts is only 50 psf, lateral displacement of the soft silt is likely. It is believed the sandy silt will also fail with the majority of this material being displaced as a mud wave. Assuming a worst case condition which is all the sandy silt beneath the dike being displaced with the exception of a 1-ft-thick layer between the fill and the silty sand, a volume of 243 yd^3 of fill per linear foot of dike constructed to el +10 ft mlw would be needed. A profile of this construction scenario is shown in Figure A7.

21. A working table should be constructed at an elevation of +2 ft mlw. The construction of this working table can most economically be accomplished by using locally dredged sands and shaping the slopes with a barge mounted crane. Once the working table has been established, the reinforcing fabric should be placed, sewn, and anchored by the use of outside fill sections. The placement and compaction of the center section should be performed only after the outside sections have been placed and compacted. The last item to be constructed is the slope protection system which should consist of a 2-ft-thick layer of rock, weighing from 130 to 180 lb each, underlain by a soil and fabric filter. To ensure adequate wave runup and protection from wave and tidal forces, the slope protection should extend the full length of the slope.



CONSTRUCTION SEQUENCE

(1) PLACE AND COMPACT FILL TO EL 2
(2) LAY FILTER CLOTH IN CONTINUOUS TRANSVERSE STRIPS AND SEW TOGETHER
(3) PLACE OUTSIDE SECTION TO ANCHOR AND STRETCH FILTER CLOTH
(4) CONSTRUCT CENTER SECTION
(5) PLACE FILTER CLOTH AND ROCK PROTECTION

VOLUME AND COST DATA

ITEM	VOLUME	COST* $/FT
FILL-DUMPED	230 YD^3/FT	1380
FILL-COMPACTED	13 YD^3/FT	98
FABRIC	15 YD^2/FT	60
EROSION PROTECTION		
ROCK**	5 YD^3/FT	150
FILTER	8 YD^2/FT	128
INSTRUMENTATION		10
SUBTOTAL		1826
CONTINGENCY (30%)		548
TOTAL		2374

*COST INCLUDES PLACEMENT

**COST BASED ON REUSING EXISTING SLOPE PROTECTION

Figure A7. Fabric-strengthened scenario for dike construction

22. The estimated costs for constructing this type of dike using slopes of 1V:4H in Bowery Bay are shown in Figure A7. The total costs, including $10/lin ft of dike for the necessary instrumentation, is about $1,900/lin ft of dike. The total dike construction costs, based on 1,700 ft of dike, is estimated to be $3.1 million without any contingency or $4 million with a 30 percent contingency.

Summary

23. As a result of this study the following statements are made:

- a. The minimum crest elevation for the containment dike should include 2 ft of freeboard if the disposal area is to contain contaminated dredged material.
- b. The possible occurrence of large mud waves of soft foundation soils is likely.
- c. An adequate factor of safety should be maintained against the possibility of a sliding failure occurring within the embankment.
- d. Large settlements within the dike and/or foundation are possible.
- e. Of the two design scenarios considered feasible for this site, the fabric-strengthened dike design is recommended for the following reasons:
  - (1) Significantly lower construction costs ($4 million for fabric-strengthened as opposed to $6 million for conventional displacement design, a savings of about 33 percent).
  - (2) Smaller volume of displaced soil (212 yd^3/lin ft of dike for fabric-strengthened as opposed to 315 yd^3/lin ft of dike for conventional displacement method, about a 33 percent reduction).

APPENDIX B: GEOTECHNICAL REPORT FOR FLUSHING BAY, NEW YORK

Introduction

1. As part of the engineering and economic feasibility study for the development of dredged material containment areas in New York Harbor, preliminary geotechnical analysis and evaluation of the potential sites were performed. The potential containment area at Flushing Bay, New York, examined in this study has been identified as such by the New York District (NYD) and the Port Authority of New York and New Jersey (PANYNJ). The purpose of this study is to describe the subsurface conditions believed to exist at this site and provide information of feasible design and construction scenarios for the containment dikes. An estimate of the construction costs and an outline of the construction sequence has been provided. This study is based on the limited subsurface data provided by the NYD and the PANYNJ, but the subsurface soil profiles and design parameters assumed in this study are believed reasonable.

Site Description

2. The proposed site, shown in Figures B1 and B2, is located in the southwest corner of Flushing Bay. The site is about 2,100 ft long and encompasses approximately 59 acres including the required dikes. The elevation of the bottom varies from 0 to -9 ft mlw with an average of -5 ft mlw. The elevation of the adjacent airport is el +10 ft mlw with a small perimeter dike designed to el +15 ft mlw.

3. The soil profiles along the west and south side of the site based on available data are shown in Figures B3 and B4. The subsurface soils beneath the proposed containment area consist of soft organic silts underlain by very dense sand. The soft organic silt varies in thickness from about 90 ft on the west to 70 ft on the east and 55 ft on the north. The average thickness of this soft silt stratum is about 64 ft. The dense to very dense sand underlying the soft organic silt extends to at least el -100 ft mlw.

General Design Considerations

4. The length of dike required to enclose the proposed disposal area is approximately 3,800 ft. The soil profile, which is believed to be representative of the average soil profile beneath the dikes, is shown in

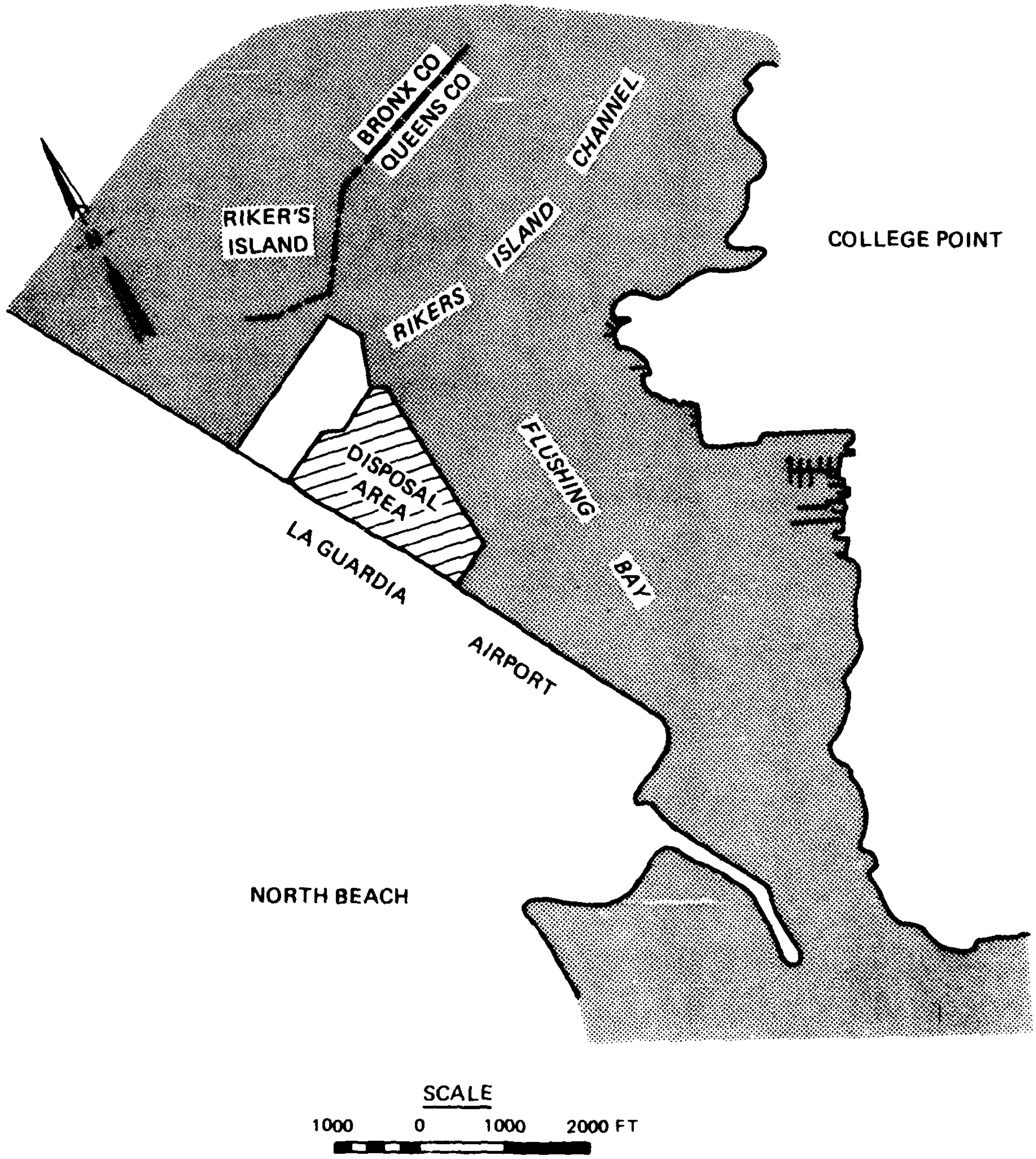


Figure B1. Location of proposed disposal area in Flushing Bay, New York

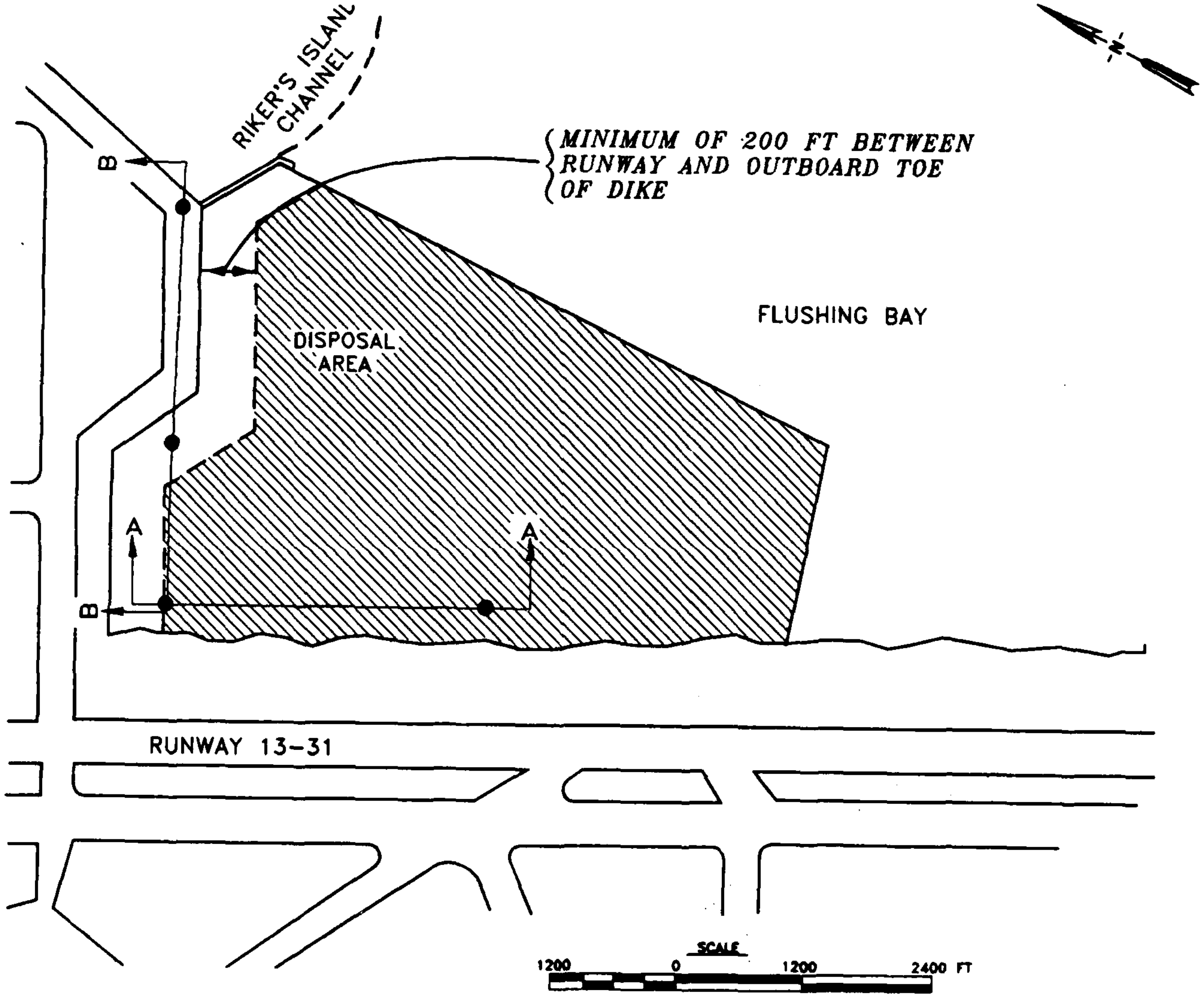


Figure B2. Location of soil profiles and retaining dike relative to runway

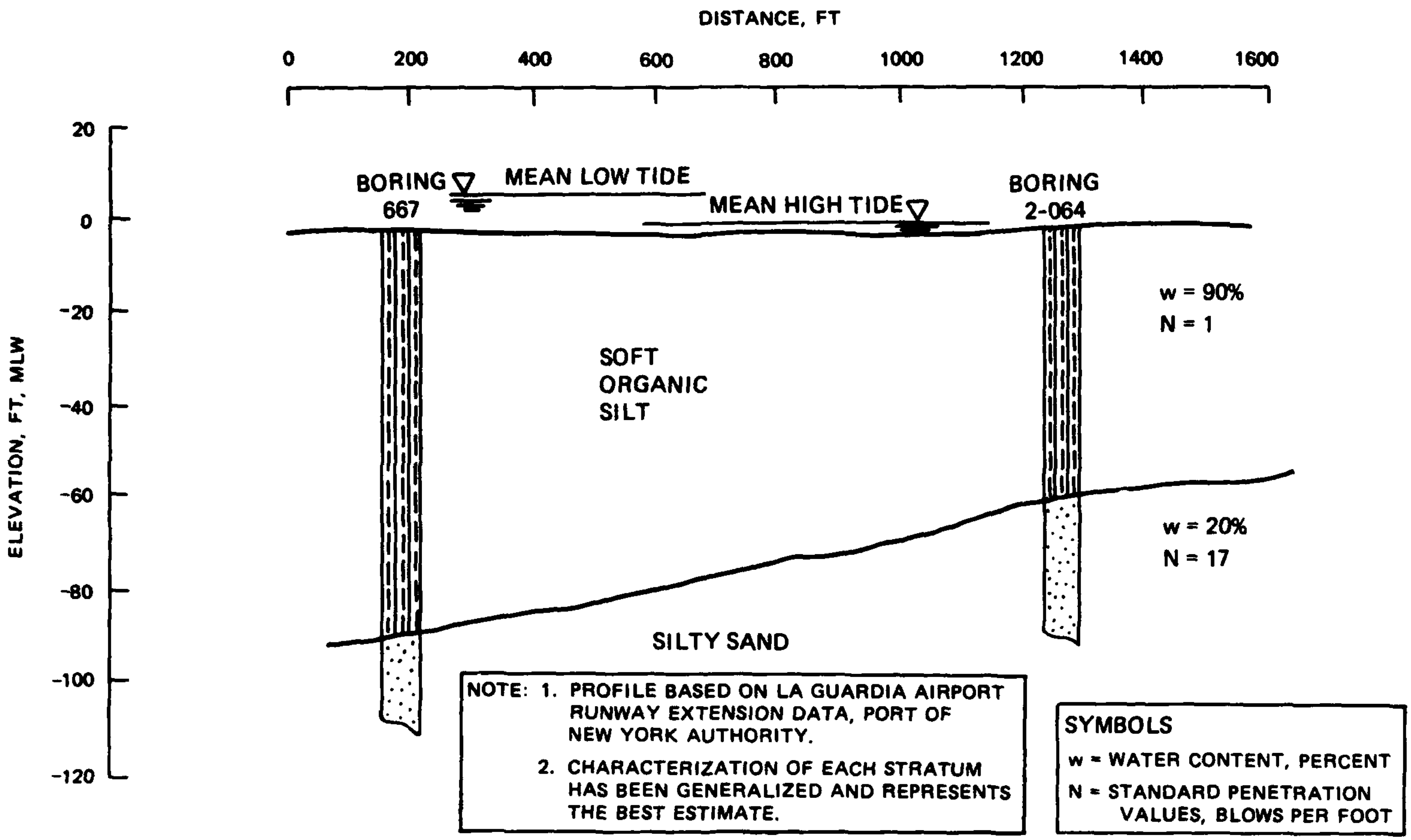
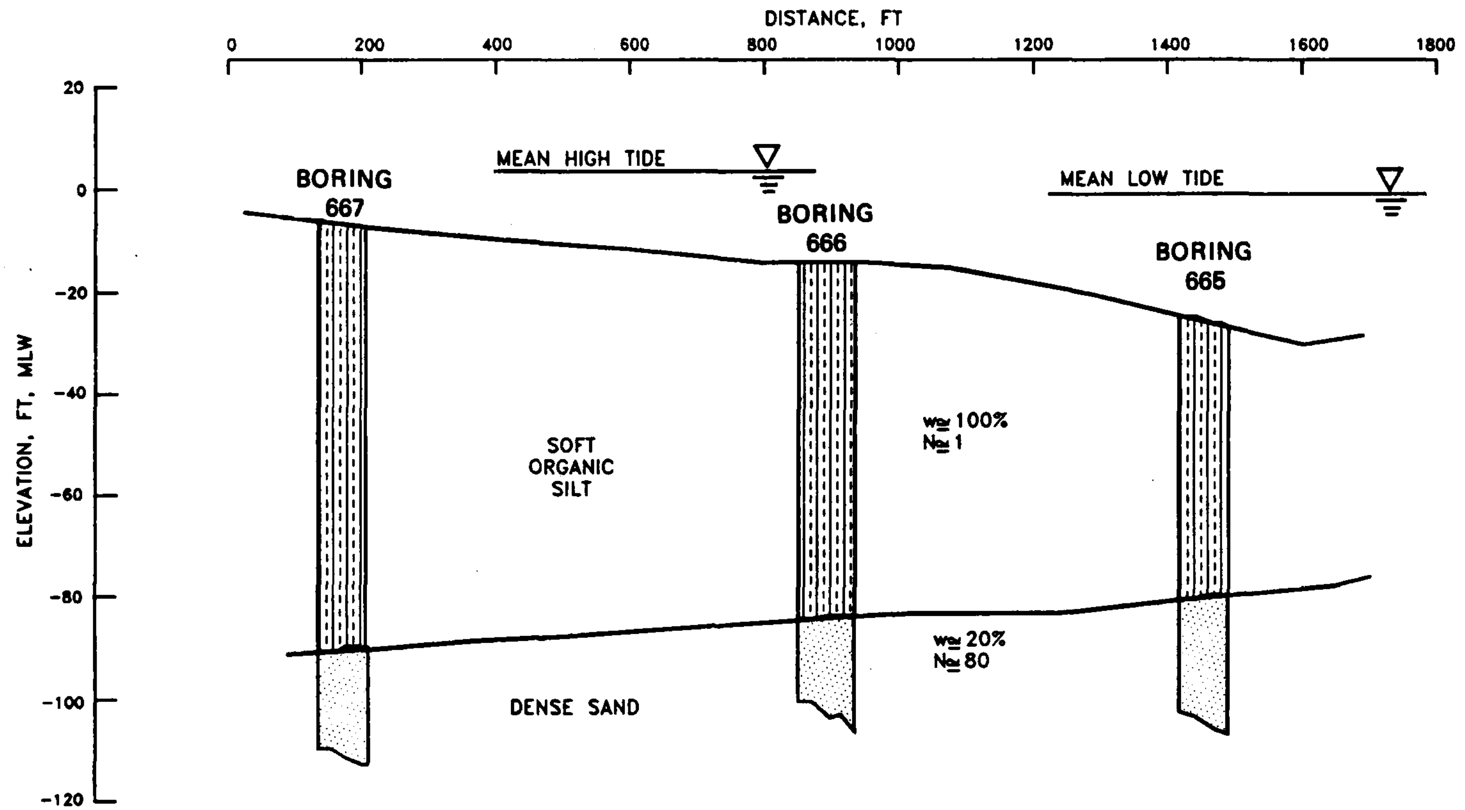


Figure B3. Soil profile section A-A



NOTE: 1. PROFILE BASED ON LA GUARDIA AIRPORT RUNWAY EXTENSION DATA, PORT OF NEW YORK AUTHORITY.

2. CHARACTERIZATION OF EACH STRATUM HAS BEEN GENERALIZED AND REPRESENTS THE BEST ESTIMATE.

SYMBOLS:
w=WATER CONTENT, PERCENT
N=STANDARD PENETRATION VALUES, BLOWS PER FOOT

Figure B4. Soil profile section B-B

Figure B5. The soil is believed to consist of soft organic silt from an average of -5 ft to -70 ft. This soft organic silt has an undrained shear strength of about 75 psf based on an equation recommended by Hough (1969). The water content is fairly uniform with depth, varying from about 85 to 120 percent with an average of 100 percent. Underlying this soft organic silt is a dense to very dense sand stratum extending from an average el -70 mlw to at least el -100 mlw. A conservative estimate of the friction angle for this sand would be 33 deg based on a relationship between friction angles and standard penetration resistance by Peck, Hanson and Thornburn (1974).*

5. An important consideration in the design of the dikes is the material which will be retained and/or the ultimate use of the site. If the site is to be used to contain contaminated dredged material, then the dikes should be of sufficient height that overtopping and subsequent flushing of the containment area will not occur. A design dike height for the containment of contaminated dredged material should include a minimum of 2 ft of freeboard above the design storm surge elevation. The storm surge elevations with corresponding frequencies are shown in Table B1; this data was provided by the NYD. If the disposal area is to be used in the creation of wetlands, no freeboard need be included in the design since any damage to the dikes from an occasional overtopping could be repaired at a cost less than constructing the dikes initially to a height that would prevent overtopping. In the creation of wetlands, retaining dikes are temporary structures, and their cost should be minimized.

6. It is recommended that at least 200 ft be maintained between the outboard toe of the dike at the mud line and the edge of the closest ship channel. There are two reasons for maintaining this distance: (a) the material outboard of the toe provides a surcharge to the underlying foundation soils, thereby increasing their bearing strength; and (b) the significant volume of soft silt which may be displaced during construction of the dikes should not be allowed to squeeze into a shipping channel.

7. At least 200 ft should be maintained between the outboard toe of the dike and any bridge or runway piling. As the dikes are constructed some of the soft silt will be displaced laterally in the form of a mud wave. If

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* References cited in this appendix are included in the References at the end of the main text.

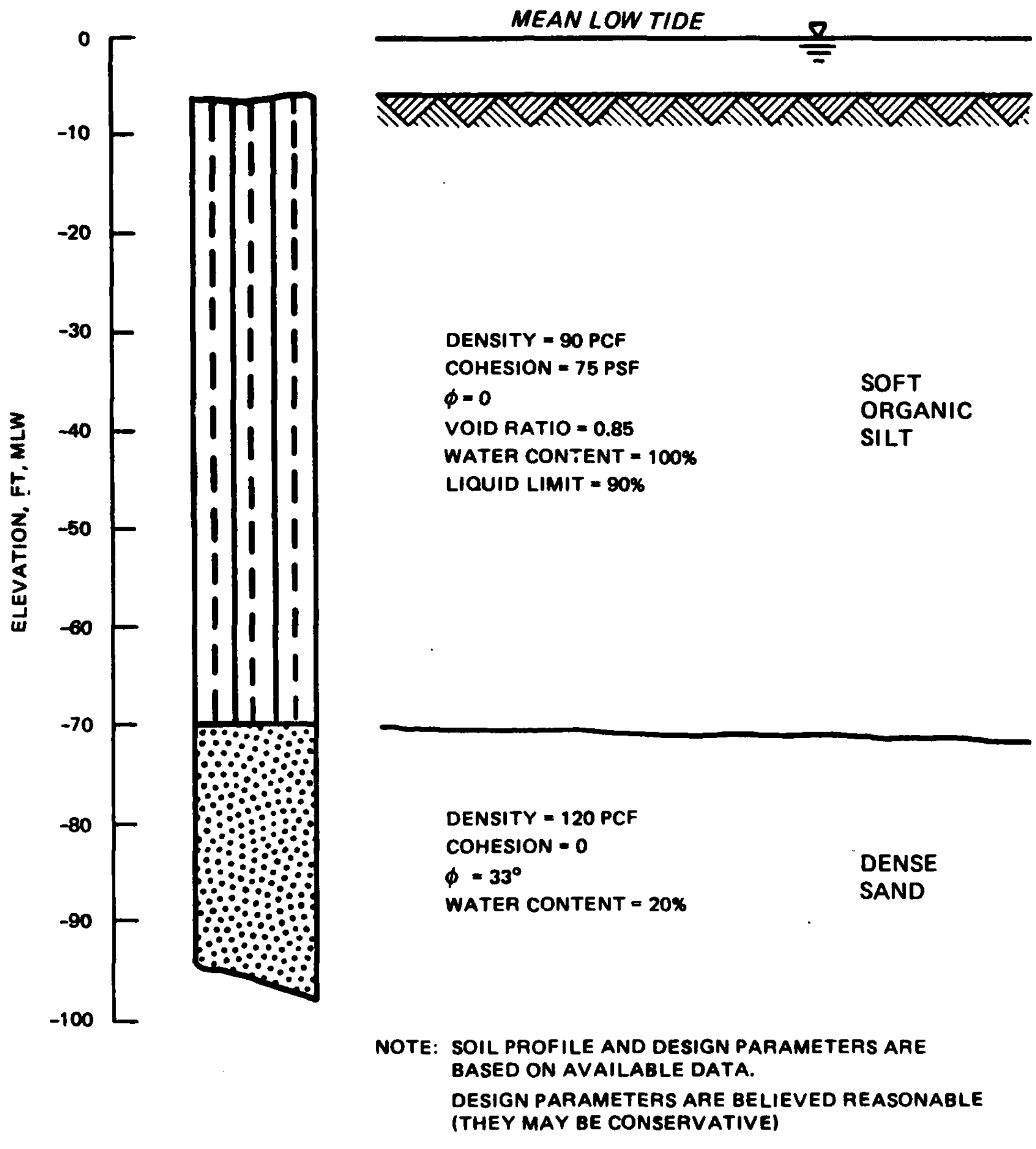


Figure B5. Assumed soil profile and design parameters for Flushing Bay disposal site

Table B1

Storm-Surge Frequencies

Frequency years	Maximum Surge Elevations ft, mlw
1	9
3	10
8	11
30	12
100	13

this material is displaced around a piling, then a lateral load could be exerted on the piling which was not anticipated in the original design. As the material desiccates and consolidates negative skin friction could be exerted which would increase the vertical loads on the piling. Two hundred feet is sufficient to significantly reduce any negative effects of containment area on the piling. The recommended minimum distance from the airport runway is shown in Figure B2.

8. The ultimate bearing capacity of the soft organic silt is approximately 400 psf, based on an equation recommended by Hammer and Blackburn (1977). A bearing capacity of 400 psf implies the organic silt could only support a dike constructed to el +0.5 ft mlw before failure occurred; therefore, it is probable that a significant amount of the soft organic silt will squeeze out from beneath the dike in the form of a mud wave during construction. A review of the logs for some borings made after Runway 13-31 was relocated to its present position showed that 15 to 25 ft of the soft organic silt was displaced as a result of constructing the runway perimeter embankment. The elevation of the airport embankment varies from 10 to 15 ft mlw which is consistent with the range of crest elevations for the required containment dikes. If the worst case condition is assumed, then the construction of the dikes would cause about 25 ft of soft organic silt to be displaced. A reasonable design, although probably conservative, would be to assume the displacement of soft organic silt extends to el -31 ft mlw.

Design and Construction Scenarios

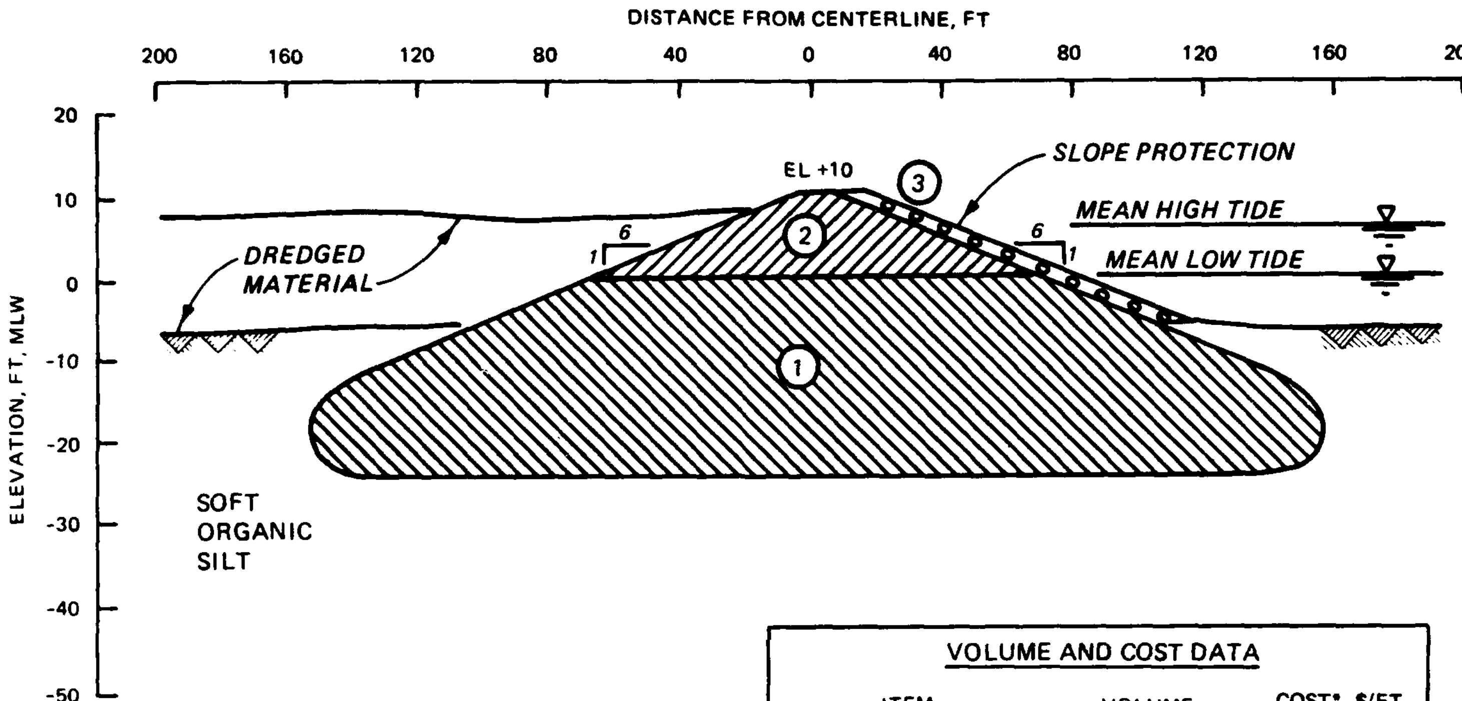
Displacement dike

9. The most common method of dike construction on soft soils is the displacement method. Basically, the method consists of allowing the dike fill to displace the weaker foundation soils until sufficient bearing has been developed to support the dike. The displaced soils often take the form of a mud wave created on either side of the dike. The two primary disadvantages to the displacement method of construction are: (a) the large volume of fill required for construction of the dike (it is possible the final constructed volume to be 10 times the original design volume); and (b) there may be objections to the creation of large mud waves.

10. The relatively high dikes required at this site and the thick deposit of soft organic silt make the displacement of large volumes of soft soils almost a certainty. There are four potentially feasible methods of reducing the displacement volumes. These methods are: (a) incremental dike raising over a period of years; (b) installation of a rigid barrier around the site (i.e., filled sheet-pile cells, etc.); (c) excavation and waste of the soft organic silts; and (d) stiffening of the dike with a reinforcement. Since the major volume of the dike is below mean high tide, incremental dike raising would not be practical. The relatively large thickness of soft organic silts make the cost for installing a rigid barrier impractical. The concept of excavating and wasting of the soft sediments is feasible; however, the dredging of the soft silts and their confinement would add a minimum of 4 to 5 million dollars to the construction costs.

11. The estimated construction volumes and costs, based on unit costs provided by the NYD and presented in Table B2 for dike slopes of 1V:6H, are shown in Figure B6. The estimated cost for the construction of the dikes is approximately $2,100/lin ft of dike. The total construction costs without a contingency would be $7.7 million or $10 million with a reasonable contingency of 30 percent. The estimate of the construction costs includes $10/lin ft of dike for instrumentation. Instrumentation is necessary for the monitoring of settlements and the changes in the pore pressures during and after construction.

12. It is recommended that the dikes have a slope of 1V:6H. The outboard side of the dike should be protected from wave and tidal degradation by



CONSTRUCTION SEQUENCE

(1) PLACE FILL TO EL 0
(2) PLACE, SHAPE, AND COMPACT DIKE FILL MATERIALS
(3) PLACE FILTER CLOTH AND ROCK PROTECTION

VOLUME AND COST DATA

ITEM	VOLUME	COST*, $/FT
FILL-UNCOMPACTED	236 YD^3/FT	1416
FILL-COMPACTED	26 YD^3/FT	195
EROSION PROTECTION		
ROCK**	8 YD^3/FT	240
FILTER	11 YD^2/FT	176
INSTRUMENTATION		10
SUBTOTAL		2037
CONTINGENCY (30%)		611
TOTAL		2648

*COST INCLUDES PLACEMENT

**COST BASED ON REUSING EXISTING SLOPE PROTECTION

Figure B6. Displacement scenario for dike construction

Table B2

Estimated Construction Unit Costs*

Construction element	Unit cost $
Dredged sand (dumped)	6.00/yd^3
Dredged sand (dumped, shaped, and densified)	7.50/yd^3
Rock (slope protection)	30.00/yd^3
Soil and fabric filter (slope protection)**	16.00/yd^2
Filter fabric (reinforcement)	4.00/yd^2

* Costs include transportation and placement.
** Cost based on filter thickness of 2 ft.

using a 2-ft-thick layer of rock underlain by a soil and fabric filter. The rock should weigh from 130 to 180 lb each and be uniformly placed in at least two lifts. The slope protection should extend the full length of the slope.

Fabric-strengthened dike

13. The concept of strengthening a dike by the use of reinforcement, such as filter fabric, is relatively new. The primary advantage of using a fabric-strengthened embankment is the ability to use steeper slopes with a subsequent savings in construction costs. A fabric-strengthened dike is similar to a floating dike where the lateral strains which occur within the embankment, both during and after construction, are controlled by use of a reinforcing material. The reinforcing fabric must have both a high elastic modulus and a high ultimate strength to withstand the large tensile stresses likely to develop within the embankment. In addition to withstanding the tensile stresses, a good reinforcing material must maximize the frictional forces developed at the soil-fabric interface. If a fabric-strengthened dike is properly designed and constructed, a failure within the reinforced section cannot occur. Therefore, slopes which would be too steep for a conventional dike can be safely used with a fabric-strengthened dike.

14. To construct a fabric-strengthened dike, a working table should be constructed at el +2 ft mlw. The construction of the working table can most economically be accomplished by using locally dredged sands and shaping the slope with a barge mounted crane. Once the working table has been established, the reinforcing fabric should be placed, sewn, and anchored by the use

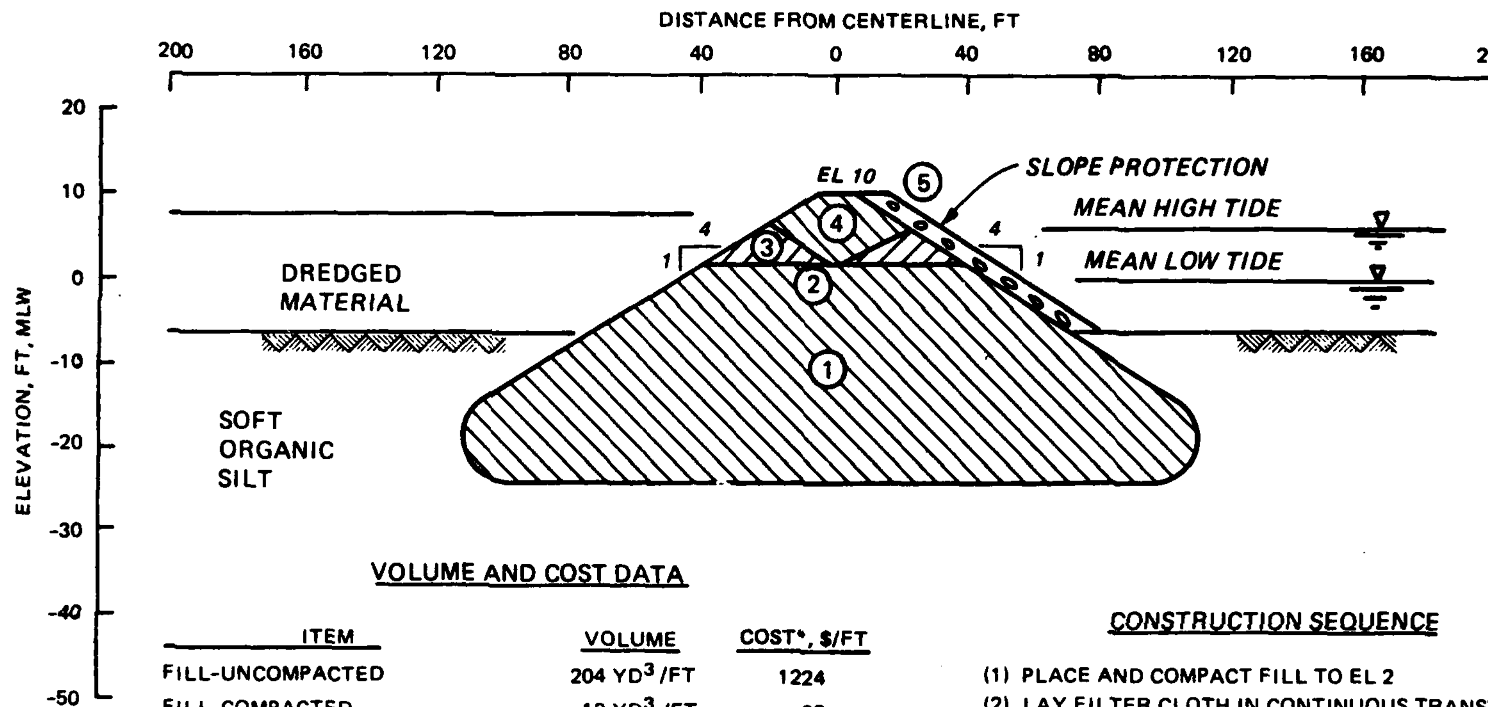
of an outside fill section. The placement and compaction of the center section should be performed only after the outside sections have been placed and compacted. The last item to be constructed should be the slope protection. The protection should consist of at least a 2-ft thick layer of rock, weighing from 130 to 180 lb each, underlain by a soil-fabric filter. To ensure adequate protection, the crushed rock and filter should extend from el -6 ft mlw to the dike crest.

15. The estimated costs for constructing a fabric-strengthened dike in Flushing Bay are shown in Figure B7. For a crest elevation of +10 ft mlw and side slopes of 1V:4H, the estimated construction costs are $1,700/lin ft of dike. This estimate includes $10/lin ft of dike for instrumentation. Based on the required dike length of 3,800 ft, the total construction costs would be about $6.3 million without any contingency or $8.2 million with a 30 percent contingency.

Summary

16. Based on an analysis of the site and probable subsurface soils, the following should be considered:

- a. The possible occurrence of large lateral displacements of soft foundation soils to el -31 ft mlw is probable.
- b. Possibility of a sliding failure occurring along the dike foundation surface could occur.
- c. Large settlements may occur within the dike and/or foundation.
- d. At least 200 ft should be maintained between the outboard toe of the dike at the mud line and the closest piling or edge of ship channel.
- e. A minimum freeboard of 2 ft for dikes used to retain contaminated dredged material or no freeboard if a wetlands is to be created.
- f. The dike should be constructed using filter fabric construction because of:
  - (1) The significantly lower construction costs ($8.2 million for a fabric-strengthened dike as opposed to $10 million for a conventional displacement).
  - (2) A significantly smaller volume of displaced soil (142 yd^3/lin ft for fabric strengthened as compared to 200 yd^3/lin ft for conventional displacement).



VOLUME AND COST DATA

ITEM	VOLUME	COST*, $/FT
FILL-UNCOMPACTED	204 YD^3/FT	1224
FILL-COMPACTED	13 YD^3/FT	93
FABRIC	12 YD^2/FT	48
EROSION PROTECTION		
ROCK	5 YD^3/FT	150
FILTER	8 YD^2/FT	128
INSTRUMENTATION	—	10
SUBTOTAL		1658
CONTENGENCY (30%)	—	498
TOTAL		2156

*COST INCLUDES PLACEMENT

CONSTRUCTION SEQUENCE

(1) PLACE AND COMPACT FILL TO EL 2
(2) LAY FILTER CLOTH IN CONTINUOUS TRANSVERSE STRIPS AND SEW TOGETHER
(3) PLACE OUTSIDE SECTION TO ANCHOR AND STRETCH FILTER CLOTH
(4) CONSTRUCT CENTER SECTION
(5) PLACE FILTER CLOTH AND ROCK PROTECTION

Figure B7. Fabric-strengthened scenario for dike construction

APPENDIX C: GEOTECHNICAL REPORT FOR NEWARK BAY, NEW JERSEY

Introduction

1. As part of the engineering and economic feasibility study for the development of dredged material containment areas in New York Harbor, a geotechnical analysis and evaluation of the potential sites were performed. The potential containment area examined in this study has been identified by the New York District (NYD) and the Port Authority of New York and New Jersey (PANYNJ) as Newark Bay, New Jersey. The purpose of this study is to describe the probable subsurface conditions existing at this site and provide information on the feasible design and construction scenarios for the containment dikes. An estimate of the construction costs and an outline of the construction sequence are presented. This study is based on limited subsurface data provided by the NYD. Thus, the subsurface soil profiles and design parameters assumed in this study are believed reasonable.

Site Description

2. The proposed site, shown in Figure C1, is located on the west side of Newark Bay south of Port Newark. The disposal area will form an island bound on the north by the Port Newark Channel, on the east by the middle reach of Newark Bay Channel, on the south by the Elizabeth Channel, and on the west by Port Newark Pierhead Channel. The port facilities in this area receive heavy use as a shipping and receiving point for containerized freight.

3. The proposed disposal area encompasses approximately 165 acres with a bottom elevation varying from 0 to -29 ft mlw with an average of el -5 ft mlw. The lack of data available on the soils beneath the proposed site required the use of an assumed profile based on logs of borings made close to the site. The borings chosen were those made about 800 ft to the north at Port Newark. Two lines of borings, one perpendicular to the other, as shown in Figure C2, were used to develop the soil profiles shown in Figures C3 and C4. Since the borings used were at least 800 ft to the north of the proposed site, extrapolating the data to the proposed site for estimating the strata and strength parameters was the only possible approach.

4. As can be seen in Figures C3 and C4, the site is probably covered with a soft organic silt with an average thickness of about 23 ft. This soft organic silt is likely underlain by a firm silty clay interbedded with layers

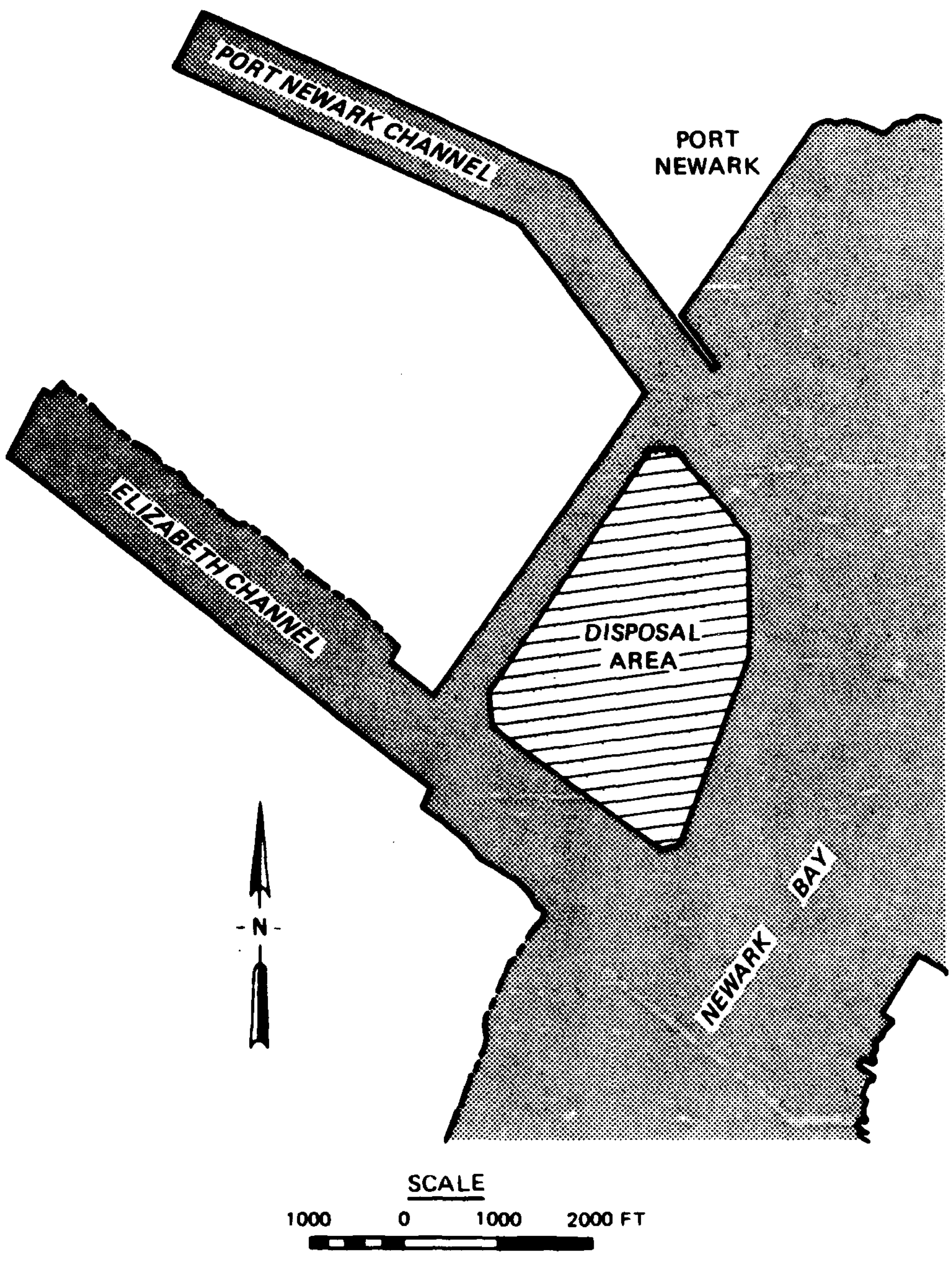


Figure C1. Location of proposed disposal area in Newark Bay, New Jersey

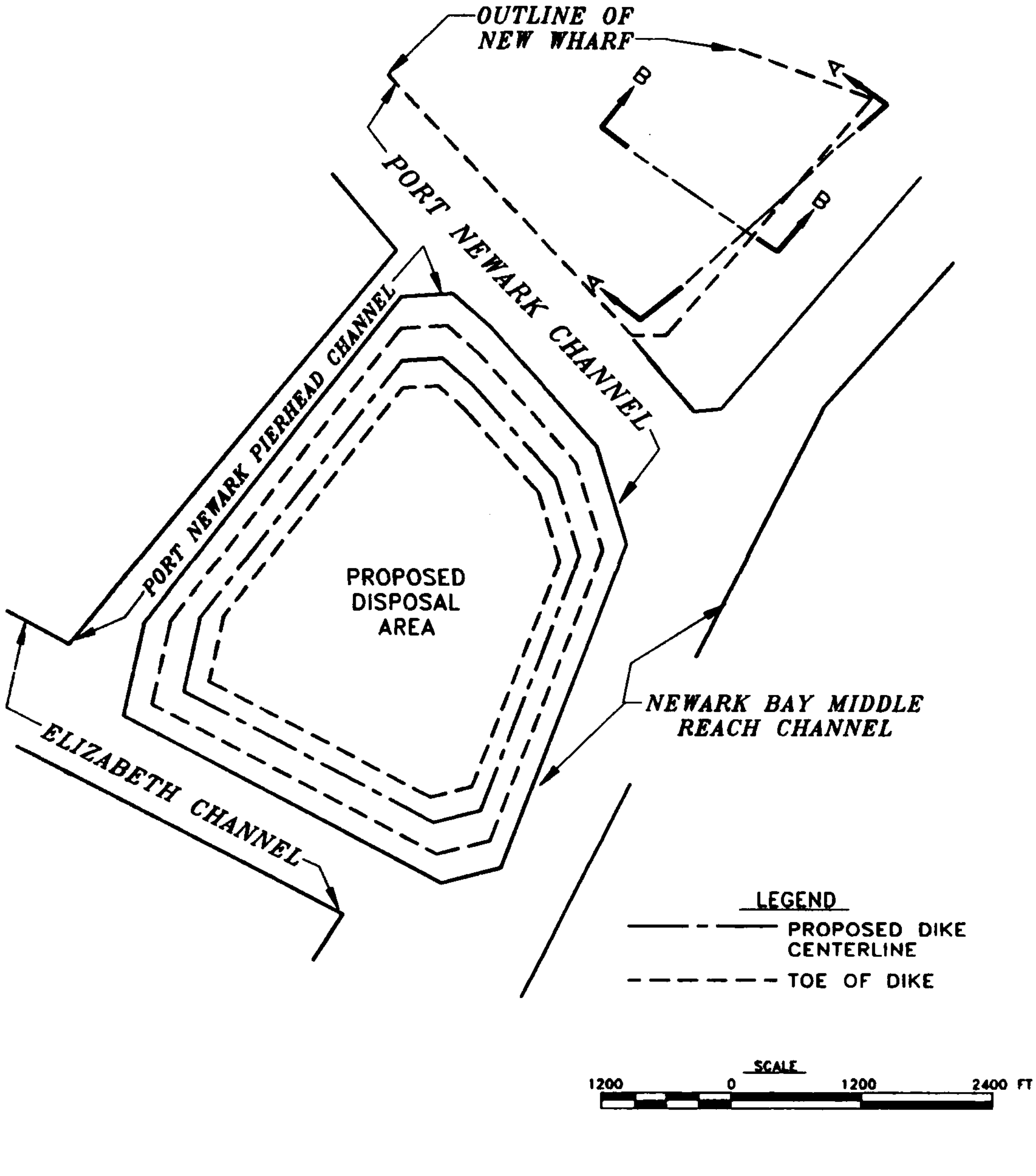


Figure C2. Location of dike and soil profile sections

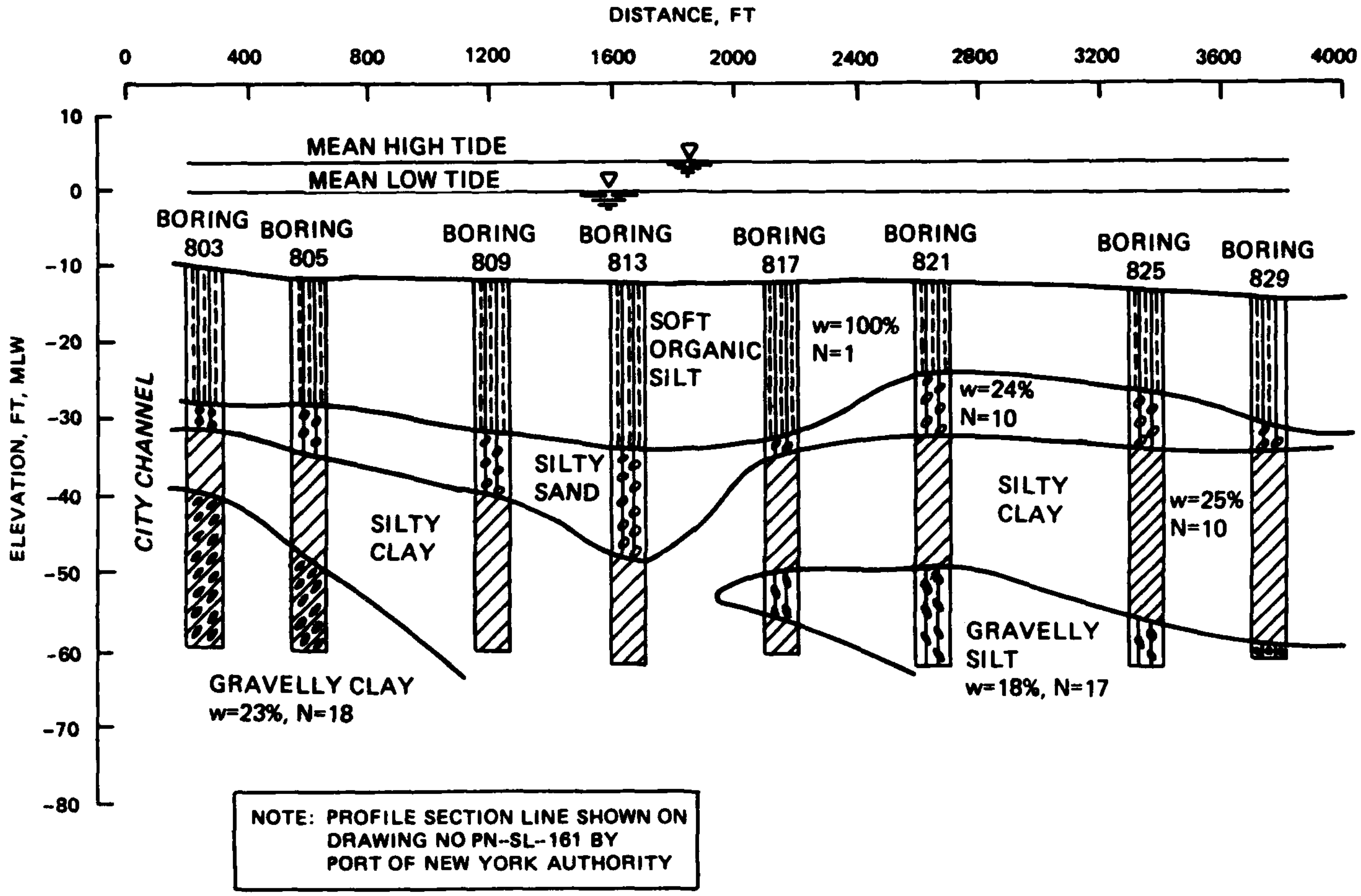


Figure C3. Soil profile A-A for Newark Bay, New Jersey

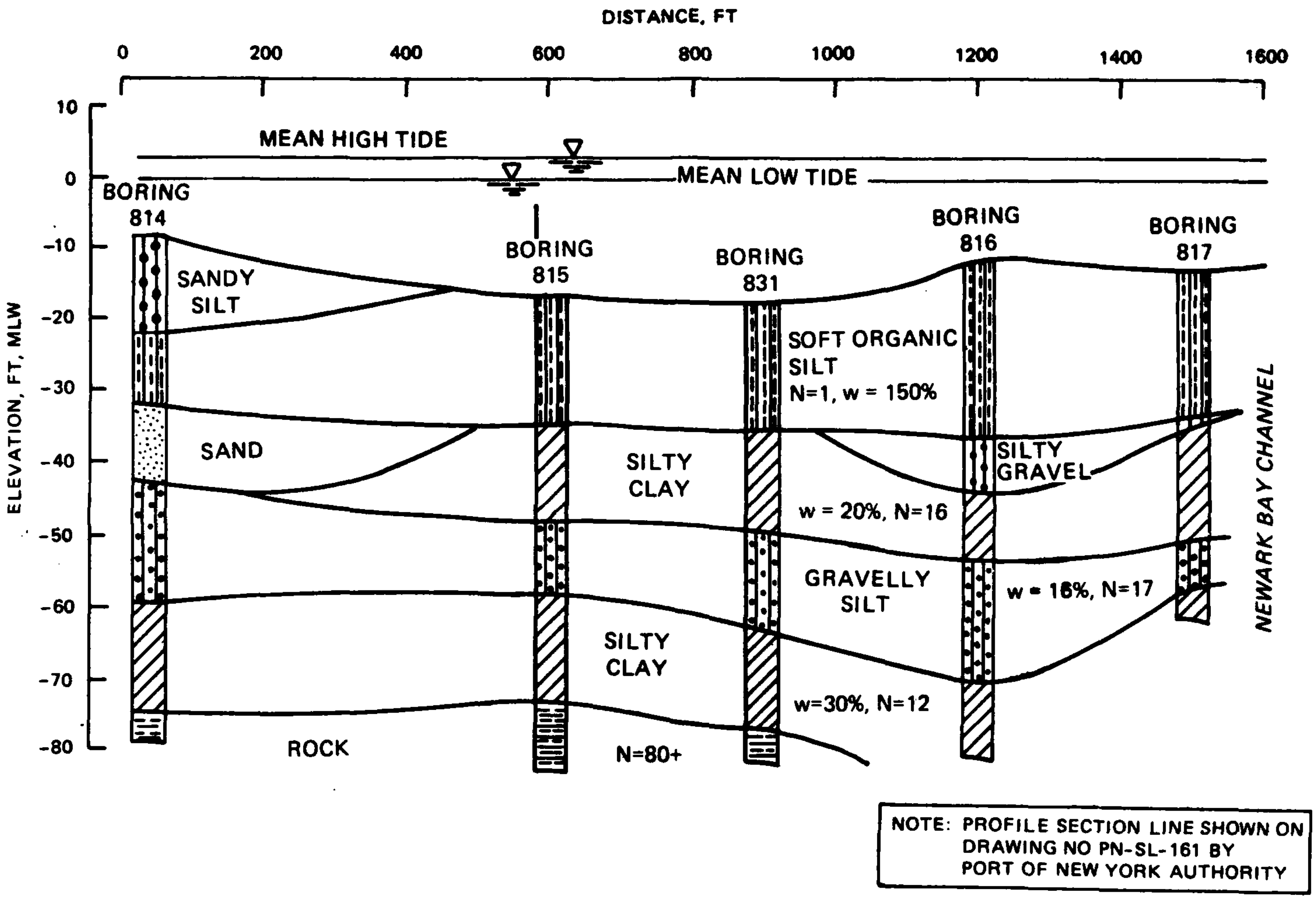


Figure C4. Soil profile B-B for Newark Bay, New Jersey

of medium-dense sand and silty sand. The silty clay and sands are probably an average of 16 ft thick. Below the silty clay and sands is a layer of firm gravelly silt and clay about 14 ft in thickness. Underlying this gravelly silt and clay is a stratum of firm silty clay about 20 ft thick overlying rock at approximately el -80 ft mlw.

General Design Conditions

5. The length of dike required to enclose the proposed disposal area is approximately 8,800 ft at the proposed dike center line. The location of the disposal area, as defined by the NYD, is shown in Figure C2. The soil profile which is believed to be representative of the average soil profile beneath the dikes, based on Figures C3 and C4, is shown in Figure C5. The soil is believed to consist of about 23 ft of soft organic silt extending from el -7 to el -30 ft mlw. This soft organic silt probably has an undrained shear strength of about 75 psf based on the relationships between standard penetration test (SPT) resistance and shear strength developed by Hough (1969).* The water content varies from 200 percent near the surface to 60 percent at the bottom. Underlying the soft organic silt is probably a silty clay extending to about el -46 ft mlw. Although the silty clay will be interbedded with sands and silty sands, they have not been shown in Figure C5 since they would have a higher strength than the silty clays. Based on the SPT values, a reasonable estimate of the undrained shear strength of this material is at least 1,000 psf. Although a profile is shown in Figure C5, borings at the actual site will be necessary prior to an actual design.

6. An important consideration in the design of the dikes is the possibility that contaminated dredged material will be retained in this site. This possibility required the dikes to be of sufficient height that overtopping and subsequent flushing of the containment area will not occur. It is recommended that the dikes be constructed to a height sufficient to provide a minimum of 2 ft of freeboard above a storm surge chosen for design. At this site, a 100-year storm surge would probably not exceed el +11 ft mlw. Shown in Table C1 are the frequencies of occurrence for several select storm surges; this data

* References cited in this appendix are included in the References at the end of the main text.

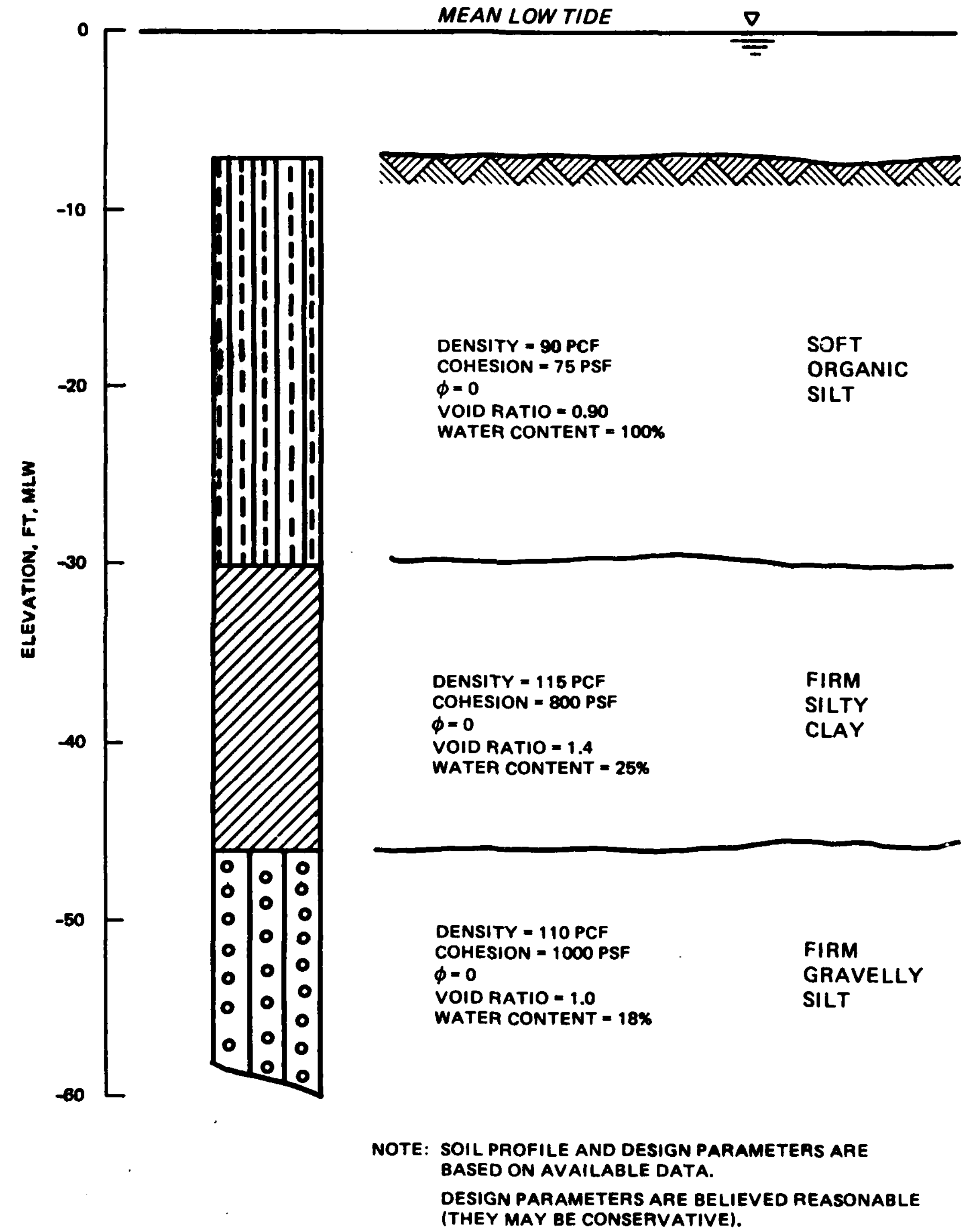


Figure C5. Assumed soil profile and design parameters

Table C1

Storm-Surge Frequencies

Frequency years	Maximum Surge Elevations ft, mlw
1	7
3	8
8	9
30	10
100	11

provided by the NYD. The surface of the surrounding port facilities has been constructed to at least el +10 ft mlw.

7. It is recommended that at least 200 ft be maintained between the outboard toe of the dike at the mud line and the edge of the closest ship channel. There are two reasons for maintaining this distance: (a) the material outboard of the toe provides a surcharge to the underlying foundation soils, thereby increasing their bearing capacity; and (b) the significant volume of soft silts which may be displaced during the construction of the dikes should not be allowed to squeeze into a shipping channel. The suggested location for the dikes in relation to the total area is shown in Figure C2.

8. The ultimate bearing capacity of the soft organic silt is approximately 400 psf, based on an equation recommended by Hammer and Blackburn (1977). A bearing capacity of only 400 psf implies the organic silt could support a dike constructed only to el 0 ft mlw before failure would occur. Therefore, it is probable that all or most of the soft silt will be squeezed out from beneath the dike in the form of a mud wave during construction. The underlying firm silty clay is believed to have an ultimate bearing capacity of about 5,000 psf and should, therefore, provide adequate bearing for the dikes. Although the underlying silts and clays should provide adequate bearing, they will consolidate under the imposed dike load.

Design and Construction Scenarios

Displacement dike

9. The most common method of dike construction on soft soils is the displacement method. Basically, the method consists of allowing the dike fill to displace the weaker foundation soils until sufficient bearing has been developed to support the dike. These displaced soils often take the form of a mud wave created on either side of the dike. The three primary disadvantages to the displacement method of construction are: (a) the large volume of fill required for the construction of the dike (it is possible for the final constructed volume to be 10 times the original design volume); (b) some objection to the creation of large mud waves; and (c) a chance the mud waves can interfere with navigation.

10. The relatively high dikes required at this site and the thick deposit of soft organic silt make the displacement of large volumes of soft soils almost a certainty. There are four potentially feasible methods of reducing the displacement volumes. These methods are: (a) incremental raising of the dike over a period of years; (b) installation of a rigid barrier around the site (i.e., filled sheet pile cells); (c) excavation and waste of the soft silts; and (d) stiffening of the dike with a reinforcement. Since the major volume of the dike fill will be below the dike surface and the site cannot be used until the crest of the dike is at least above mean high tide (el +5 ft mlw), incremental dike raising would not be practical. The relatively thick deposit of soft silts requires that an artificial barrier extend into the subsoils to at least el -50 ft mlw. A sheet pile barrier extending from el +12 to el -50 ft mlw and encompassing the site would cost at least $75 million; therefore, this option is probably not practical. The concept of excavating and wasting the soft sediments is feasible; however, the dredging of the soft silts and their confinement would add a minimum of $10 million to the costs associated with a strengthened dike construction scenario.

11. Estimated unit costs, provided by the NYD, are shown in Table C2. The total estimated construction costs and design volumes for the displacement method of construction are shown in Figure C6. The estimated cost for the construction of the dikes is approximately $2,800/lin ft of dike which would make the total cost about $24 million without a contingency or $32 million with a reasonable 30 percent contingency. The estimate of the construction

Table C2

Estimated Construction Unit Costs*

Construction element	Unit cost $
Dredged sand (dumped)	$6.00/yd^3$
Dredged sand (dumped, shaped, and densified)	$7.50/yd^3$
Rock (slope protection)	$30.00/yd^3$
Soil and fabric filter (slope protection)**	$16.00/yd^2$
Filter fabric (reinforcement)	$4.00/yd^2$

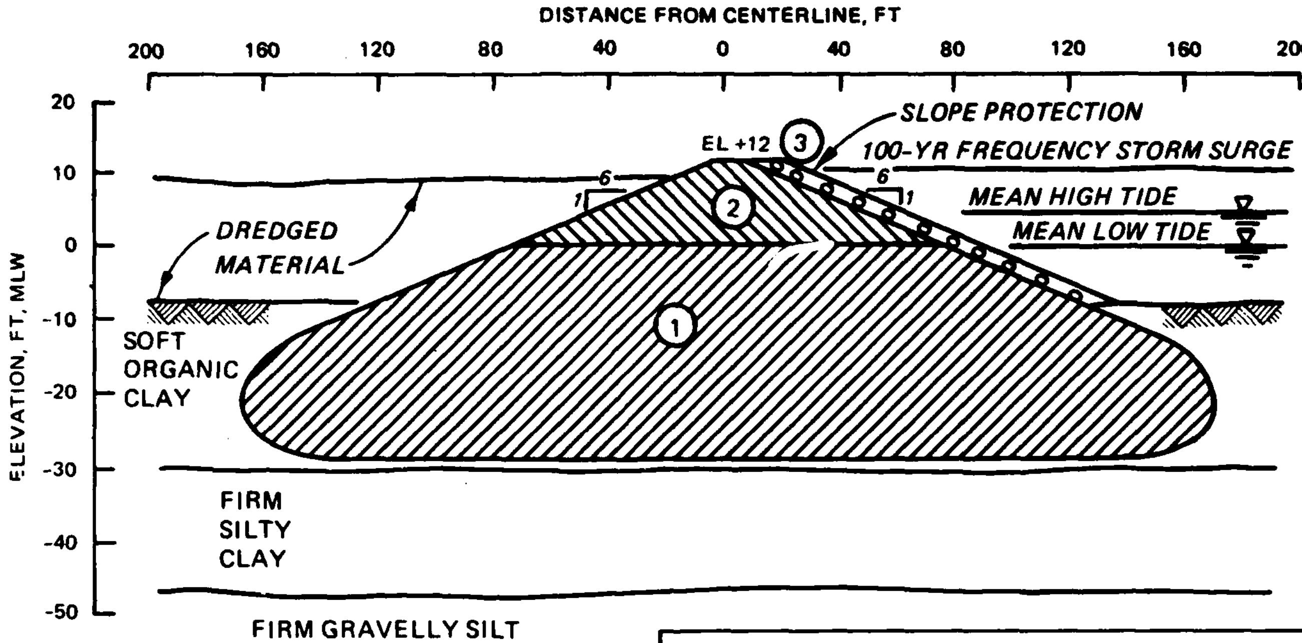
* Costs include transportation and placement.
** Cost based on filter thickness of 2 ft.

costs includes $10/lin ft of dike for instrumentation. Instrumentation is necessary for the monitoring of settlements and changes in the pore pressures during and after construction.

12. It is recommended that the outboard side of the dike be protected from wave and tidal degradation by using a 2-ft-thick layer of rock underlain by a soil and fabric filter. The rock should weigh from 130 to 180 lb each and be uniformly placed in at least two lifts. The slope protection system should extend the full length of the slope from el -7 ft mlw to the crest.

Fabric-strengthened dike

13. The concept of strengthening a dike by the use of reinforcement, such as filter fabric, is relatively new. The primary advantage of using a fabric-strengthened embankment is the ability to use steeper slopes with a subsequent savings in construction costs. A fabric-strengthened dike is similar to a floating dike where the lateral strains which occur within the embankment, both during and after construction, are controlled by the use of a reinforcing material. The reinforcing fabric must have both a high elastic modulus and a high ultimate strength to withstand the large tensile stresses likely to develop within the embankment. In addition to withstanding the tensile stresses, a good reinforcing material must maximize the frictional forces developed at the soil-fabric interface. If a fabric-strengthened dike is properly designed and constructed, a failure within the reinforced section cannot occur. Therefore, slopes which would be too steep for a conventional dike can be safely used with a fabric-strengthened dike.



CONSTRUCTION SEQUENCE

(1) USE DREDGED SANDS TO CONSTRUCT A WORKING PLATFORM AND DIKE BASE AT EL 0

(2) BUILD DIKE SECTION USING DREDGED SANDS, SHAPE AND DENSIFY FILL DURING CONSTRUCTION

(3) PLACE FILTER FABRIC AND ROCK PROTECTION

VOLUME AND COST DATA

ITEM	VOLUME	COST*, $/FT
DISPLACEMENT FILL	328 YD^3/FT	1968
DENSIFIED DIKE FILL	37 YD^3/FT	278
EROSION PROTECTION		
ROCK	9 YD^3/FT	270
FILTER	13 YD^2/FT	208
INSTRUMENTATION		10
SUBTOTAL		2734
CONTINGENCY (30%)		820
TOTAL		3554

*COST INCLUDES PLACEMENT

Figure C6. Displacement scenario for dike construction to retain contaminated dredged material at Newark Bay, New Jersey

14. Since the upper 23 ft of foundation soils is a soft organic silt with an average shearing strength of 75 psf, failure and subsequent displacement of most of the soft silt is probable. The soil underlying the organic silt is a firm silty clay which is likely to adequately support the dike. Assuming a worst case condition in which all of the soft organic silt with an exception of 1 ft between the fill and firm silty clay stratum is displaced, a volume of 273 yd^3 of fill per linear foot of dike would be needed based on a crest elevation of +12 ft mlw. A profile of this construction scenario is shown in Figure C7.

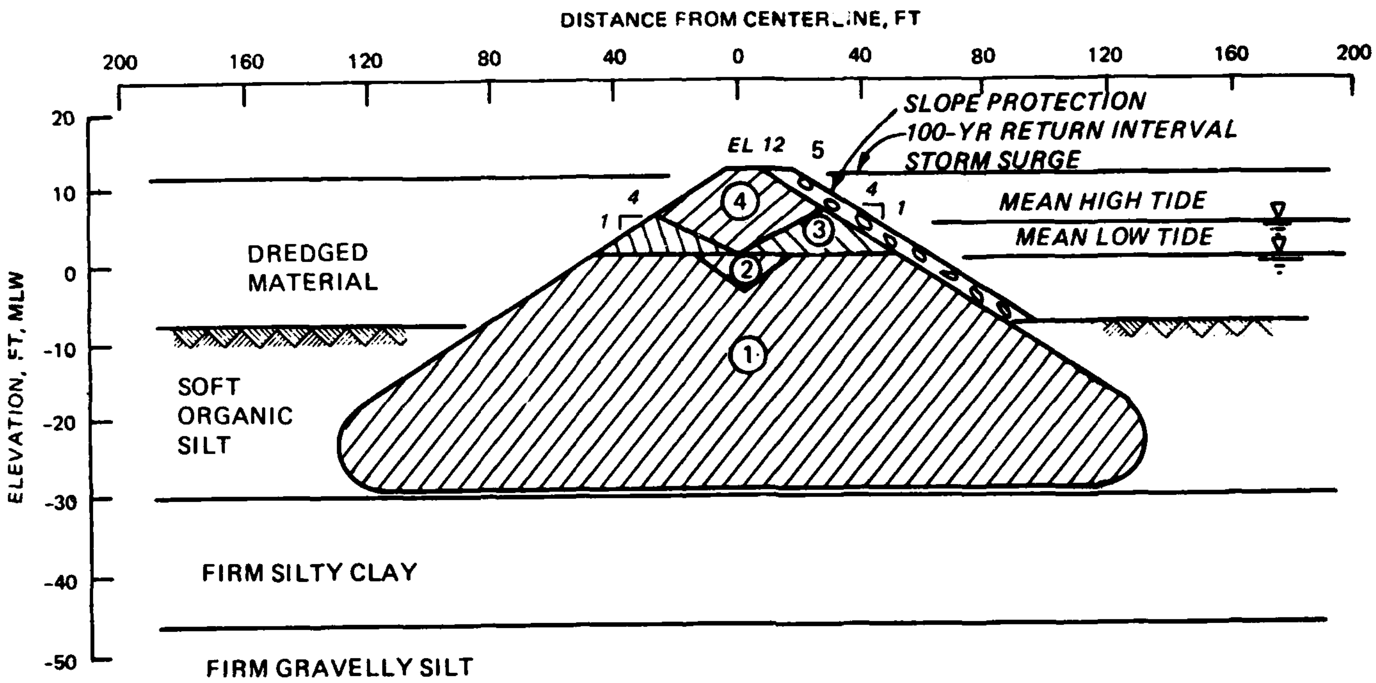
15. A working table should be constructed at el +2 mlw. The construction of this working table can most economically be accomplished by using dredged sands and shaping the slope with a barge-mounted crane. Once the working table has been established, the reinforcing fabric should be placed, sewn, and anchored by the use of an outside fill section. The placement and compaction of the center section should be performed only after the outside sections have been placed and compacted. The last item to be constructed should be the slope protection. The protection should consist of at least a 2-ft layer of crushed rock, weighing from 130 to 180 lb each, underlain by a soil fabric filter. To ensure adequate protection, the crushed rock and filter should extend from el -7 ft mlw to the dike crest.

16. The estimated costs for constructing a fabric-strengthened dike in Newark Bay is shown in Figure C7. The estimated construction costs are approximately $2,100/lin ft of dike. This amount includes $10/lin ft of dike for the necessary instrumentation. Based on the required dike length of 8,800 ft, the total construction costs would be about $18.4 million without any contingency or $24 million with a 30-percent contingency.

Summary

17. Based on an analysis of the site and probable subsoils, the following should be considered:

- a. The minimum crest elevation of dikes should include 2 ft of freeboard if the site is to be used to retain contaminated dredged material.
- b. The possible occurrence of large lateral displacements of soft foundation soils is likely.



CONSTRUCTION SEQUENCE

(1) PLACE AND COMPACT FILL TO EL 2
(2) LAY FILTER CLOTH IN CONTINUOUS TRANSVERSE STRIPS AND SEW TOGETHER
(3) PLACE OUTSIDE SECTION TO ANCHOR AND STRETCH FILTER CLOTH
(4) CONSTRUCT CENTER SECTION
(5) PLACE FILTER CLOTH AND ROCK PROTECTION

VOLUME AND COST DATA

ITEM	VOLUME	COST*, $/FT
FILL	254 YD^3/FT	1524
FILL-COMPACTED	19 YD^3/FT	143
FABRIC	22 YD^2/FT	88
EROSION PROTECTION		
ROCK	6 YD^3/FT	180
FILTER	9 YD^2/FT	144
INSTRUMENTATION		10
SUBTOTAL		2089
CONTENGENCY (30%)		625
TOTAL		2714

*COST INCLUDES PLACEMENT

Figure C7. Fabric-strengthened scenario for dike construction to retain contaminated dredged material at Newark Bay, New Jersey

c. At least 200 ft should be maintained between the outboard toe of the dike at the mudline and the edge of the closest ship channel.

d. An adequate factor of safety should be maintained against the possibility of a sliding failure occurring within the embankment.

e. Large settlements may occur within the dike and/or foundation.

f. A fabric-strengthened dike is recommended for the following reasons:

(1) Significantly lower construction costs ($24 million for a fabric-strengthened dike as opposed to $32 million for a conventional displacement).

(2) Significantly smaller volume of displaced soil mud wave (213 yd^3/lin ft of dike for a fabric-strengthened dike as opposed to 298 yd^3/lin ft of dike for conventional displacement method of construction).

APPENDIX D: GEOTECHNICAL REPORT FOR RARITAN BAY, NEW JERSEY

Introduction

1. As part of the engineering and economic feasibility study for the development of containment areas in New York Harbor, a geotechnical analysis and evaluation of the sites were performed. The potential containment area examined in this study was identified as Raritan Bay, New Jersey, by the New York District (NYD) and the Port Authority of New York and New Jersey (PANYNJ). The purpose of this study is to describe the general subsurface conditions believed to exist at the site based on available information, develop feasible design scenarios, identify any constraints for the construction of the containment dikes, suggest a preliminary dike design, and estimate the construction costs. This study is based on limited subsurface data provided by the NYD; however, the subsurface soil profiles and design parameters used in this study are believed reasonable.

Site Description

2. The proposed containment area is located in the northwestern portion of Raritan Bay next to South Amboy, NJ, and approximately 1 mile southwest of Staten Island, NY. As shown in Figure D1, the site is bordered on the north by the Raritan River and Arthur Kill ship channels and on the west and south by South Amboy. The site is divided into three areas of consideration as identified in Figure D1 as A, B, and C.

3. Area A is approximately 6,300 ft long and 2,300 ft wide. It encompasses approximately 278 acres and will require the construction of 16,100 ft of retaining dike. The average elevation of the bottom is about -1 ft mlw. The area is bordered by designated wetlands area on the west. The site extends south almost to the protection structures for the outfall of Cheesequake Creek. Adjoining the disposal site on the north is the containment area designated as Area B. This area is about 2,000 ft long and 1,400 ft wide with a surface area of approximately 72 acres. If site B is connected to site A, then an additional 3,300 ft of dike will be needed. Site B is bordered by an area being developed on the west. The average bottom elevation in this area is about -1 ft mlw. Disposal Area C is north of Area B and borders the Amboy Junction port facilities.

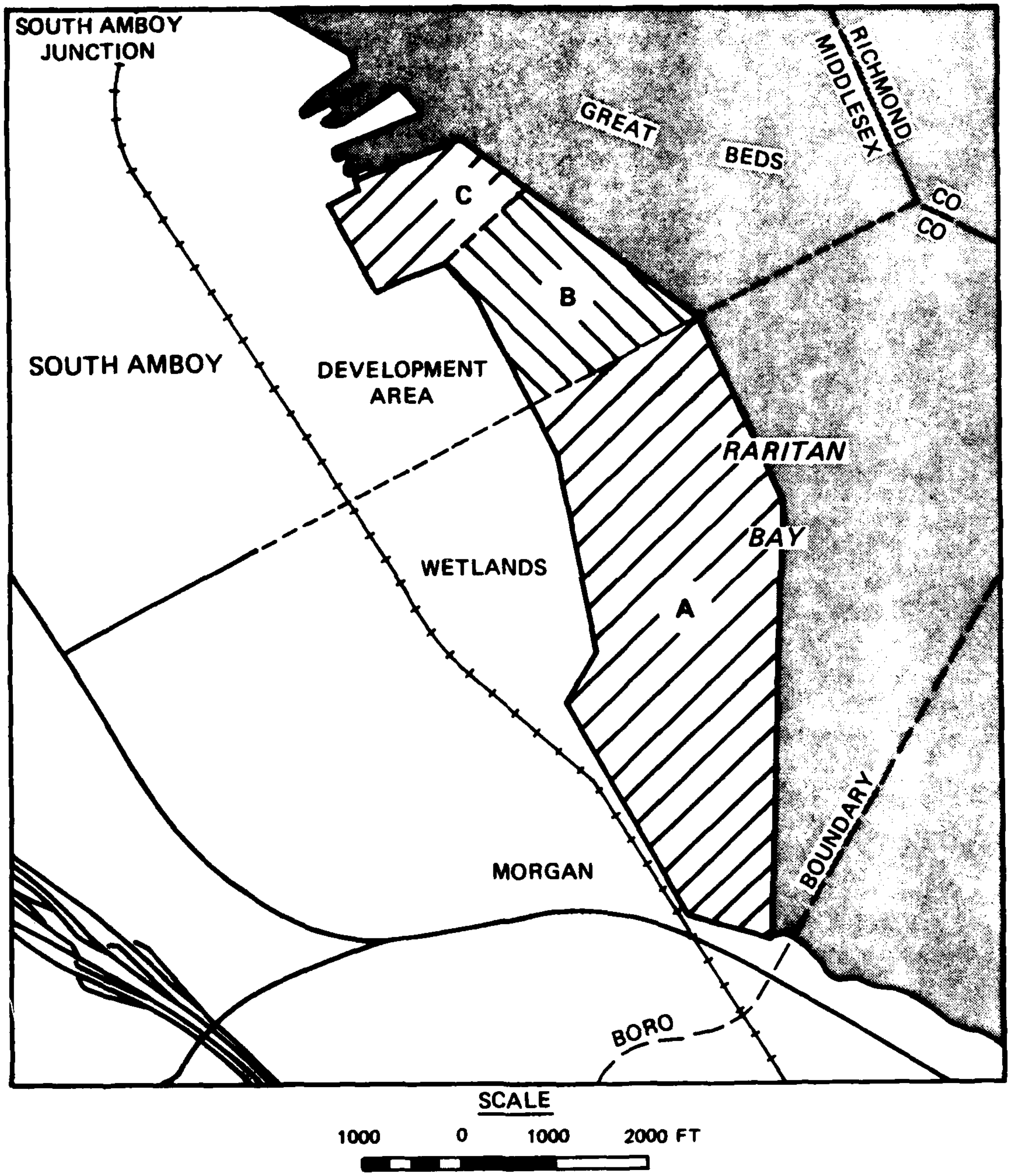


Figure D1. Location and configuration of proposed disposal area

Area C encompasses approximately 40 acres which would require an additional 3,100 ft of dike if this area is to be included with Areas A and B. The bottom elevation in Area C varies from 0 to -5 ft mlw with an average of -2 ft mlw.

4. There are currently several structures in Area C which make this site unattractive as a potential disposal area. On the west side of the area is a shiploading dock which appears usable. In addition, a sewage disposal facility located on the west of the site discharges into the area through a submerged outfall. These two major structures may need to be relocated.

5. An assumed soil profile along the shore of Raritan Bay, based on available data, is shown in Figure D2. As shown in the figure, the subsurface soils beneath the proposed containment site consist primarily of soft to very soft organic silts with lens of fine sand to a depth of 40 ft. Underlying these very soft silts is a medium dense fine sand extending to an undetermined depth. It should be noted that approximately 10,000 ft to the south of the proposed containment site, the subsurface soils consist primarily of fine sands with little organic silts.

General Design Considerations

6. The major design consideration in the construction of the containment dikes is the existing foundation soils. Based on an examination of the penetration tests conducted for the purpose of river planning by the NYD, extremely soft foundation soils exist beneath the majority of the site.

7. The surface elevation of the foundation soils vary from el 0 ft mlw on the east to el -5 ft mlw on the west, with an average elevation along the proposed center line of the outboard dikes of -3.3 ft mlw. The foundation soils consist of a very soft organic silt with interbedded thin sand lenses down to approximately el -40 ft mlw. Based on the penetration tests performed by the NYD using a 300-lb hammer and two different casing sizes with two different hammer fall heights and known relationships between penetration resistance and soil strength given by Hough (1969),* a design value for the average cohesion was estimated to be 75 psf. This value agrees with that

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* References cited in this appendix are included in the References at the end of the main text.

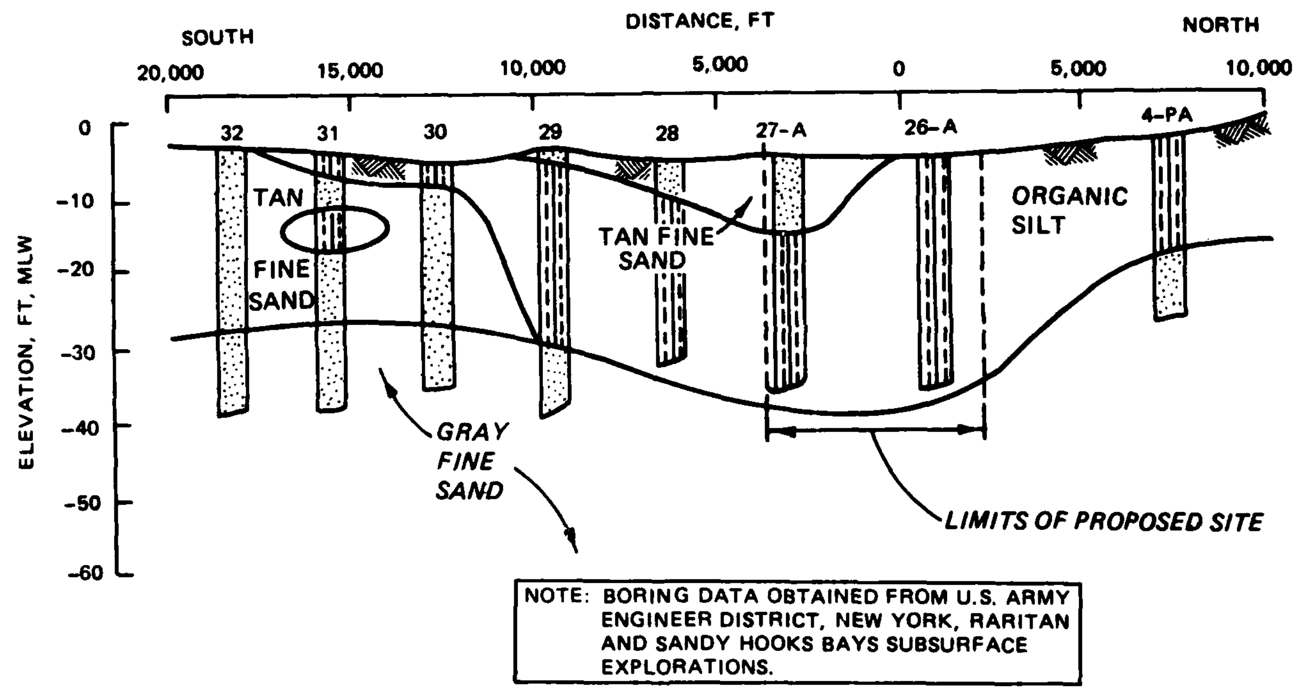


Figure D2. Assumed soil profile alongshore based on available data

expected based on experience in working with similar soils. Penetration tests along the coastal regions both north and south of the proposed disposal area indicate that the organic silt stratum may actually vary in thickness from a few feet to more than 40 ft; therefore, assuming the thickness of the silt to be about 37 ft represents the probable worst case. Below the stratum of organic silt is a medium-dense poorly graded fine sand which extends to an undetermined depth. The assumed soil profile and parameters used in the design and construction scenarios are shown in Figure D3.

8. The design of the containment dikes must consider four potential failure modes: (a) overtopping and subsequent erosion of the dike materials by storm surges, high tides, and/or wakes caused by shipping; (b) bearing failure of the soft foundation either during or immediately after construction; (c) slope failure caused by either rotating or sliding of the dike along the soft foundation soils; and (d) excessive settlement which could significantly reduce the storage capacity of the site and/or cause failure within the dike.

9. Ultimate bearing capacity for the soft foundation soil is approximately 400 psf, based on an equation recommended by Hammer and Blackburn (1977). This low bearing strength prohibits construction of the dikes to an elevation greater than +2 ft mlw without failure of the foundation. The foundation failure would take the form of large amounts of the soft organic silt being displaced laterally as construction proceeds. This lateral displacement of soil would result in the formation of a mud wave which often occurs when constructing dikes on this type of soil. Since mean high tide is at an elevation of +6 ft mlw, a dike constructed to an elevation of only +2 ft mlw would be of little value in serving as a containment structure; therefore, if large displacements of foundation materials (mud waves) are to be avoided, special design and construction procedures must be used.

10. An important consideration in the design of the dikes is the material which will be retained and/or the ultimate use of the site. If the site is to be used to contain contaminated dredged material, then the dikes should be of sufficient height that overtopping and subsequent flushing of the containment area will not occur. A design dike height for the containment of contaminated dredged material should include a minimum of 2 ft of freeboard above the design storm surge elevation. The storm surge elevations with corresponding frequencies are shown in Table D1; this data was provided by the

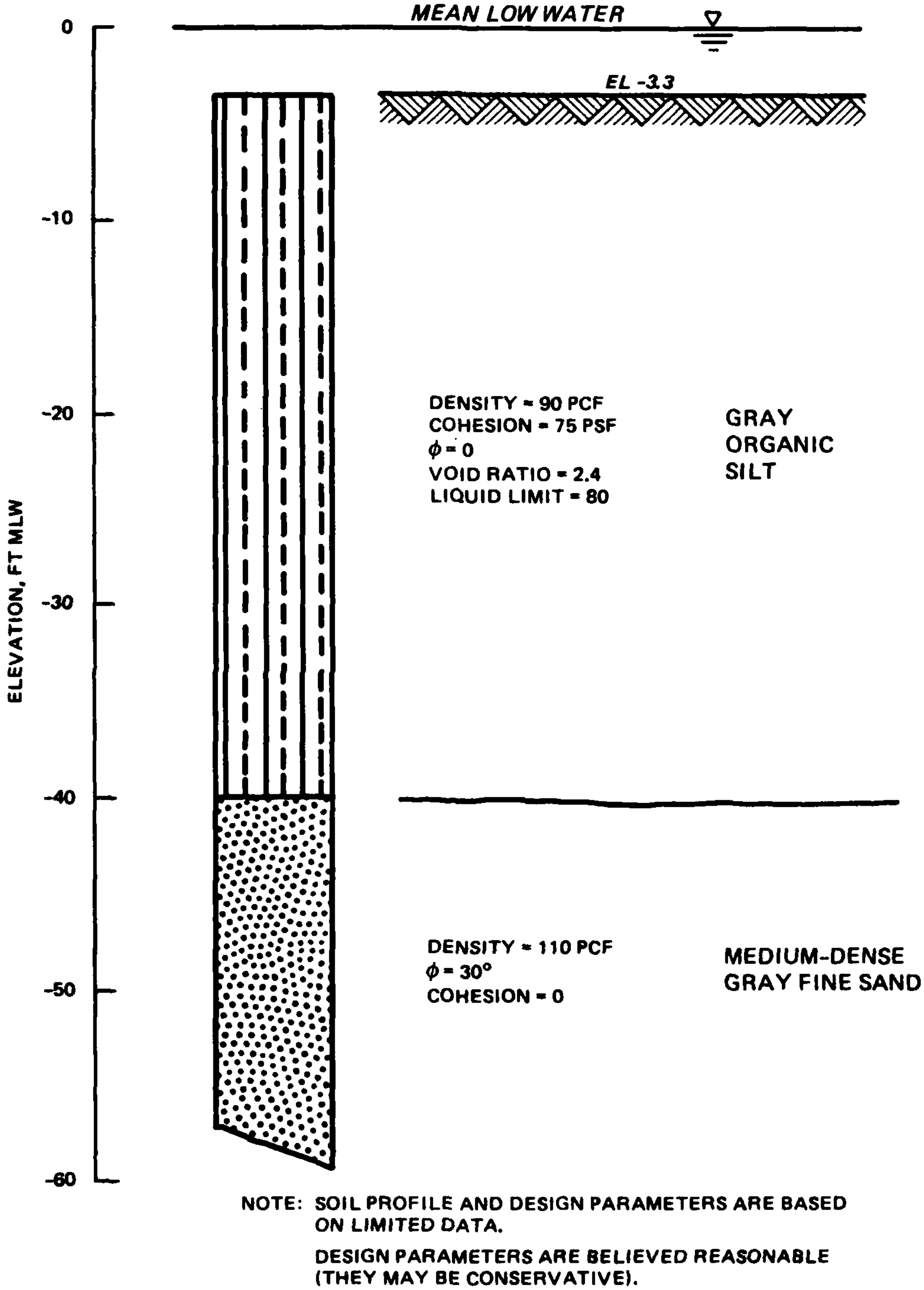


Figure D3. Assumed soil profile and design parameters for dike foundation

Table D1

Storm-Surge Frequencies

Frequency years	Maximum Surge Elevations ft, mlw
1	9
3	10
8	11
30	12
100	13

NYD. If the disposal area is to be used in the creation of wetlands, no freeboard need be included in the design since any damage to the dikes from an occasional overtopping could be repaired at a cost less than constructing the dikes initially to a height that would prevent overtopping. In the creation of wetlands, retaining dikes are temporary structures, and their cost should be minimized.

11. A problem associated with this site is the proximity of the state wetlands area as shown in Figure D1. Because of the thickness of the underlying soft silts, there is a good possibility that mud waves may form during construction of the dikes. The formation of these mud waves can be controlled by excavating and replacing a portion of the soft silts below the proposed dikes. This technique would reduce the amount of material displaced by strengthening the foundation.

Design and Construction Scenarios

Excavation and replacement

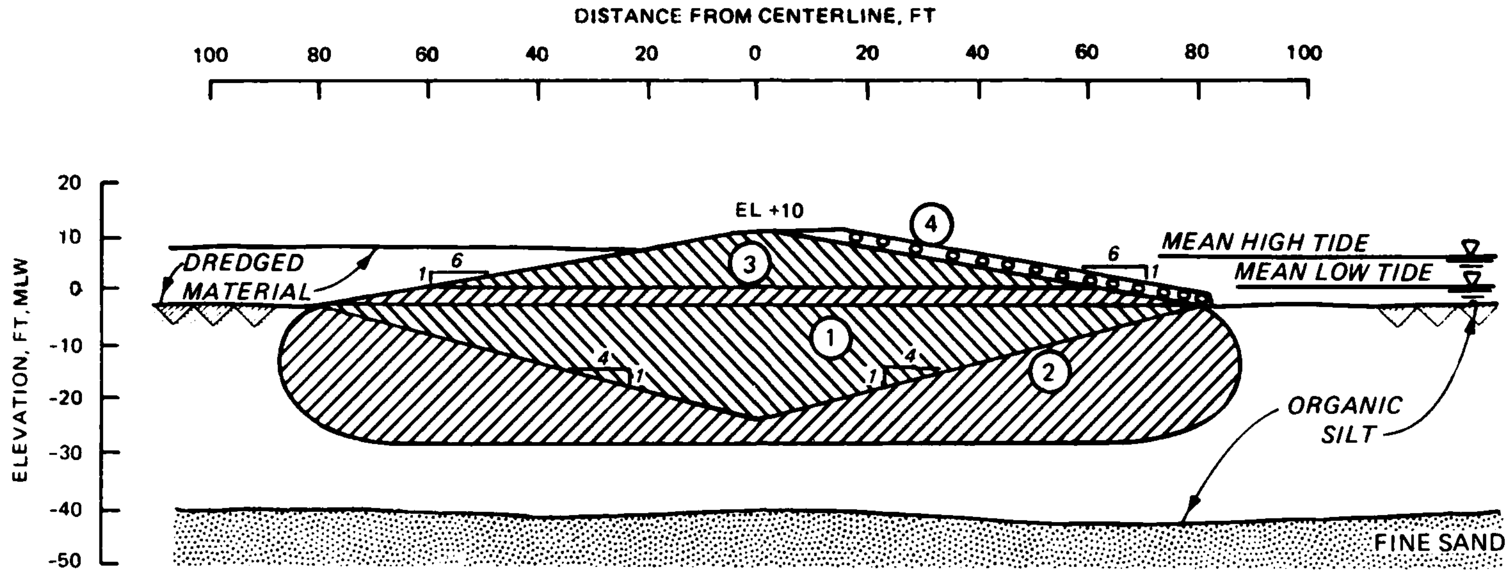
12. When it is necessary to construct dikes on very soft foundation soils, an option which is available to the designer/planner is the excavation of the soft soils and replacement with a granular material. Although this option often results in a stronger foundation with a larger factor of safety in sliding of the embankment and lower settlements than that for other design scenarios, it is also generally the most expensive.

13. Because of the weak foundation soils which exist at this site, complete excavation of the underlying material is unnecessary. If the existing soft materials are excavated to el -24 ft mlw with a 1V:4H slope as shown in Figure D4, then further excavation will not be necessary. The material to be excavated is primarily an organic silt unsuitable for use as dike fill; therefore, the construction of a smaller interior disposal area will be required.

14. It is recommended that dredged sand be placed to an elevation of +1 ft mlw to provide a working platform on which to construct the remaining portion of the dike. The material used above el +1 ft mlw can be obtained from locally available land borrows and should be compacted in 6-in. lifts to a slope not steeper than 1V:6H. The outboard slope of the dikes should be protected from erosion and degradation caused by tidal and wave action by using a uniformly placed 2-ft-thick layer of rock underlain by an appropriate fabric and soil filter. The rock should weigh from 130 to 180 lb each. The slope protection should extend from the toe to the crest of the dike to provide for adequate wave runup.

15. The cost for this design and construction scenario is estimated to be about $1,500/lin ft of dike based on the unit cost data provided by the NYD shown in Table D2. If a 30-percent contingency factor is added to the estimated cost, a more realistic construction cost would be approximately $1,900/lin ft of dike. The breakdown of the estimated costs and suggested construction sequence is shown in Figure D4. It should be noted that included in the estimated construction costs is $10/lin ft of dike for instrumentation. Instrumentation is necessary for the monitoring of settlement and the buildup and dissipation of pore pressures during and after construction.

16. This form of dike construction should be used along the southwest side of the disposal site next to the wetland area. The partial excavation will reduce the size of the mud wave likely to be formed during construction. Because of the relatively high construction cost for this design scenario, it is unlikely that all the dike would be constructed using this technique. If this scenario is used in the complete length of dike, then the construction costs would be approximately $23.7 million for Area A, $28.6 million for Areas A and B, and $33.2 million for Areas A, B and C. These costs do not include any contingency; therefore, if a 30 percent contingency is included, the costs would be about $30.9 million for Area A, $37.2 million for Areas A and B, and $43.1 million for Areas A, B and C.



CONSTRUCTION SEQUENCE	
(1)	HYDRAULICALLY DREDGE TO EXCAVATION LIMITS SHOWN
(2)	HYDRAULICALLY FILL EXCAVATED AREA WITH SANDS TO EL 0
(3)	END-DUMP AND SHAPE DIKE WITH SELECT BORROW
(4)	PLACE FILTER CLOTH AND ROCK PROTECTION

VOLUME AND COST DATA

ITEM	VOLUME	COST*, \$/FT
EXCAVATION (DREDGE)	64 YD^3/FT	263
CONTAINMENT (EXCAV)	64 YD^3/FT	32
MOB AND DEMOB		10
FILL (DREDGED)	167 YD^3/FT	685
COMPACTED FILL	26 YD^3/FT	149
EROSION PROTECTION		
ROCK	6 YD^3/FT	180
FILTER	9 YD^2/FT	144
INSTRUMENTATION		10
SUBTOTAL		1473
CONTINGENCY (30%)		442
TOTAL		1915

Figure D4. Excavation and fill scenario for dike construction

Table D2

Estimated Construction Unit Costs*

Construction element	Unit cost $
Excavation (dredged)**	4.10/yd^3
Dredged sand (dumped)	4.10/yd^3
Fill (land borrow)†	5.70/yd^3
Rock (slope protection)	30.00/yd^3
Soil and fabric filter (slope protection)††	16.00/yd^2
Filter fabric (reinforcement)	4.00/yd^2

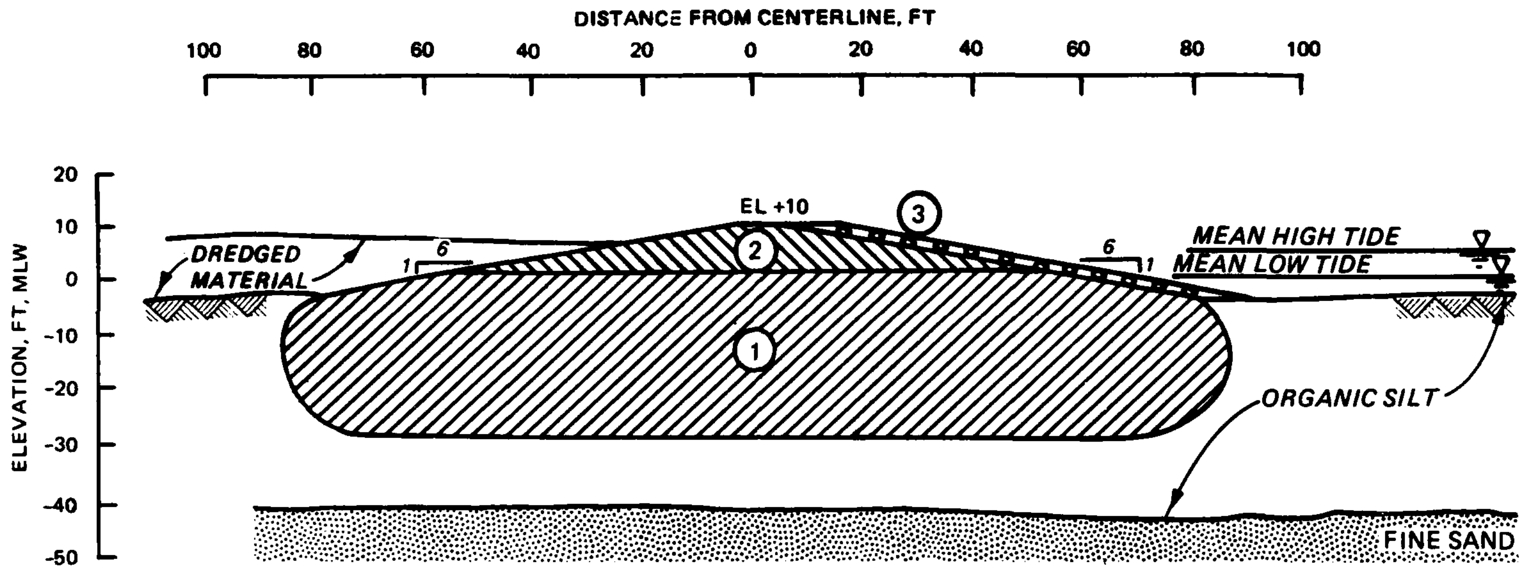
* Costs include transportation and placement.
** Cost includes containment.
† Cost includes placing, shaping, and densifying.
†† Cost based on filter thickness of 2 ft.

Displacement dike

17. The displacement form of dike construction is probably the most common method of constructing retaining dikes over soft foundation soils. This method of construction consists primarily of overstressing the soft foundation soils with subsequent compression and lateral displacement of the soft material. The displacement of the soft underlying material will probably take the form of a mud wave which is commonly associated with this type of construction. The displacement of the foundation material will continue until sufficient soft underlying soil has been replaced with the stronger fill soil to allow the dike to be constructed to the desired elevation. The amount of soil which must be displaced to create sufficient strength to support the dike is dependent on a number of variables including the strength and thickness of the soft soils.

18. Based on previous experience in constructing containment dikes on soft foundation soils, it is estimated that for every cubic yard of constructed dike at least 10 yd^3 of foundation soils will either be compressed or displaced. Because of the large volume of fill required to compensate for the displacement and settlement likely to occur, dredging of the locally available fine sands is the most cost effective means of obtaining the required fill.

19. The estimated construction volumes for dike slopes of 1V:6H and corresponding construction costs are shown in Figure D5. Included in the



CONSTRUCTION SEQUENCE

(1) HYDRAULICALLY DREDGE LOCAL SANDS TO FILL LIMITS AT EL +1

(2) END-DUMP, SHAPE AND COMPACT DIKE WITH SELECT BORROW

(3) PLACE FILTER CLOTH AND ROCK PROTECTION

VOLUME AND COST DATA

ITEM	VOLUME	COST*, $/FT
DISPLACEMENT FILL (DREDGE)	167 YD^3/FT	685
MOB AND DEMOB		10
COMPACTED DIKE FILL	26 YD^3/FT	149
EROSION PROTECTION		
ROCK	6 YD^3/FT	180
FILTER	9 YD^2/FT	144
INSTRUMENTATION		10
SUBTOTAL		1178
CONTINGENCY (30%)		354
TOTAL		1532

*COST INCLUDES PLACEMENT

Figure D5. Displacement scenario for dike construction

proposed design is a slope protection system consisting of a 2-ft-thick layer of 130- to 180-lb rock underlain by a fabric and soil filter system. This system will provide adequate protection against erosion and/or degradation of the dike slopes as a result of tidal or wave action. The slope protection system system should extend the full length of the slope to provide for adequate wave runup. The estimated cost for this design scenario is about $1,200/lin ft of dike or $1,600/lin ft of dike if a 30-percent contingency is included. As discussed in the previous design scenario, $10/lin ft of dike has been included for instrumentation which is necessary to evaluate the actual performance.

20. The cost of constructing the retaining dike using this design scenario is about $21.1 million for Area A, $25.0 million for Areas A and B, and $28.7 million for Areas A, B and C. If a 30-percent contingency is included, the costs would be approximately $27.4 million for Area A, $32.5 million for Areas A and B, and $37.3 million for Areas A, B and C. The costs are based on using the excavation and replacement construction technique for the 7,100 ft of dike next to the wetlands area.

Floating dike

21. The concept of floating a containment dike on very soft subsurface soils, such as those that exist at this site, is fairly new but has been used successfully at several sites with a significant savings in construction costs. The basis of the design is that the lateral strains which occur within an embankment during and after construction are controlled by the use of specially selected reinforcing material (such as filter fabric). The reinforcing material must be high strength and have a sufficiently high elastic modulus to withstand the large tensile stresses which are likely to develop while providing for maximum development of the contact frictional forces. If the embankment has been designed properly, the embankment is prevented from failure within the reinforced section, and subsequently, any localized failure within the embankment is prevented. In addition, as lateral strains develop within the embankment, internal arching of the soil occurs, transmitting the vertical stresses toward the outside edges and resulting in a more uniform distribution of the bearing stresses.

22. Since the average elevation of the surface of the foundation along the proposed center line of the dike is -1 ft mlw, a working platform must be constructed prior to placing any fabric reinforcement. Based on a bearing

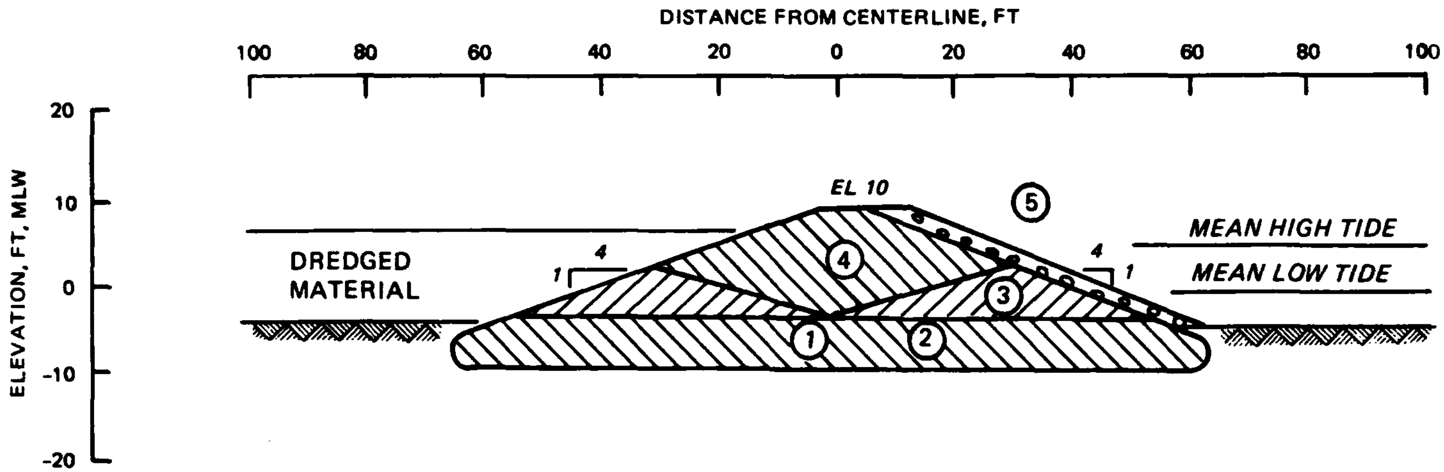
strength of 400 psf, a working table can be constructed to at least el +1 ft mlw without a bearing failure. The most economical construction technique would be to end-dump locally available borrowed fill to develop a compact working table. Since the dike will float on the surface of the soft soils rather than displace them, large volumes of fill, as required in the first two design scenarios, will not be necessary. A representative dike profile and construction with volume and cost data are given in Figure D6.

23. The reinforcing fabric should be placed on the working table constructed to el +1 ft mlw and properly anchored on the ends by use of the outside fill sections. The placement and compaction of the center section should be performed only after the outside sections have been placed and compacted to ensure proper development of the tensile stresses in the reinforcement. The last item to be constructed is the slope protection system, and as discussed previously, it should consist of a 2-ft-thick layer of 180-lb rock underlain by a fabric and soil filter. The slope protection should extend from the toe to the dike crest to ensure adequate wave runup and protection from wave and tidal forces.

24. The estimated cost of constructing this type of dike with a slope of 1V:4H, as shown in Figure D6, is approximately $630/lin ft of dike which includes $10/lin ft of dike for the necessary instrumentation. If a 30-percent contingency is included, the cost is $820/lin ft of dike. Because of the special design considerations which are involved in this construction method, it is important that a proper subsurface exploration and laboratory testing program be performed.

25. The construction costs associated with using a floating dike around the disposal area is about $10.1 million for Area A, $12.2 million for Areas A and B, and $14.2 million for Areas A, B, and C. The costs would be $13.1 million for Area A, $15.9 million for Areas A and B, and $18.5 million for Areas A, B, and C if a 30-percent contingency is included. Because the volume of displaced soil is significantly less with the floating dike as compared to a displacement dike, partial excavation of the foundation would be unnecessary.

26. The costs for this scenario are approximately one-half of those for the displacement scenario. This is because a working platform can be constructed to el +1 ft mlw and the fabric placed before the foundation fails in



VOLUME AND COST DATA

ITEM	VOLUME	COST*, $/FT
FILL	55.0 YD^3/FT	314
FABRIC	22.0 YD^2/FT	88
EROSION PROTECTION		
ROCK	4.0 YD^3/FT	120
FILTER	6.0 YD^2/FT	96
INSTRUMENTATION		10
SUBTOTAL		628
CONTINGENCY (30%)		188
TOTAL		816

*COST INCLUDES PLACEMENT

CONSTRUCTION SEQUENCE

(1) END-DUMP AND COMPACT FILL TO EL 2
(2) LAY FILTER CLOTH IN CONTINUOUS TRANSVERSE STRIPS AND SEW TOGETHER
(3) PLACE OUTSIDE SECTION TO ANCHOR AND STRETCH FILTER CLOTH
(4) CONSTRUCT CENTER SECTION
(5) PLACE FILTER CLOTH AND ROCK PROTECTION

Figure D6. Floating dike construction scenario

bearing. The floating dike scenario is further enhanced by the close proximity of good land borrow.

Summary

27. Based on the three construction scenarios considered feasible for this site, the floating dike scenario is recommended for the following reasons:

- a. It is now proven technology and is the lowest cost.
- b. The displacement dike volumes and subsequent costs, shown in Figure D4, could be low.
- c. The mud wave likely to be created will be significantly lower than the displacement form of construction and comparable to the excavation and replacement scenario.
- d. The costs for the floating dike are based on known and available land borrows for the fill whereas the costs for the displacement dike are based on a significant amount of the fill being locally dredged.
- e. The displacement method of construction and associated dredging may have a more negative impact on the biological ecosystem of Raritan Bay as compared to a floating dike.

The following additional statements are made:

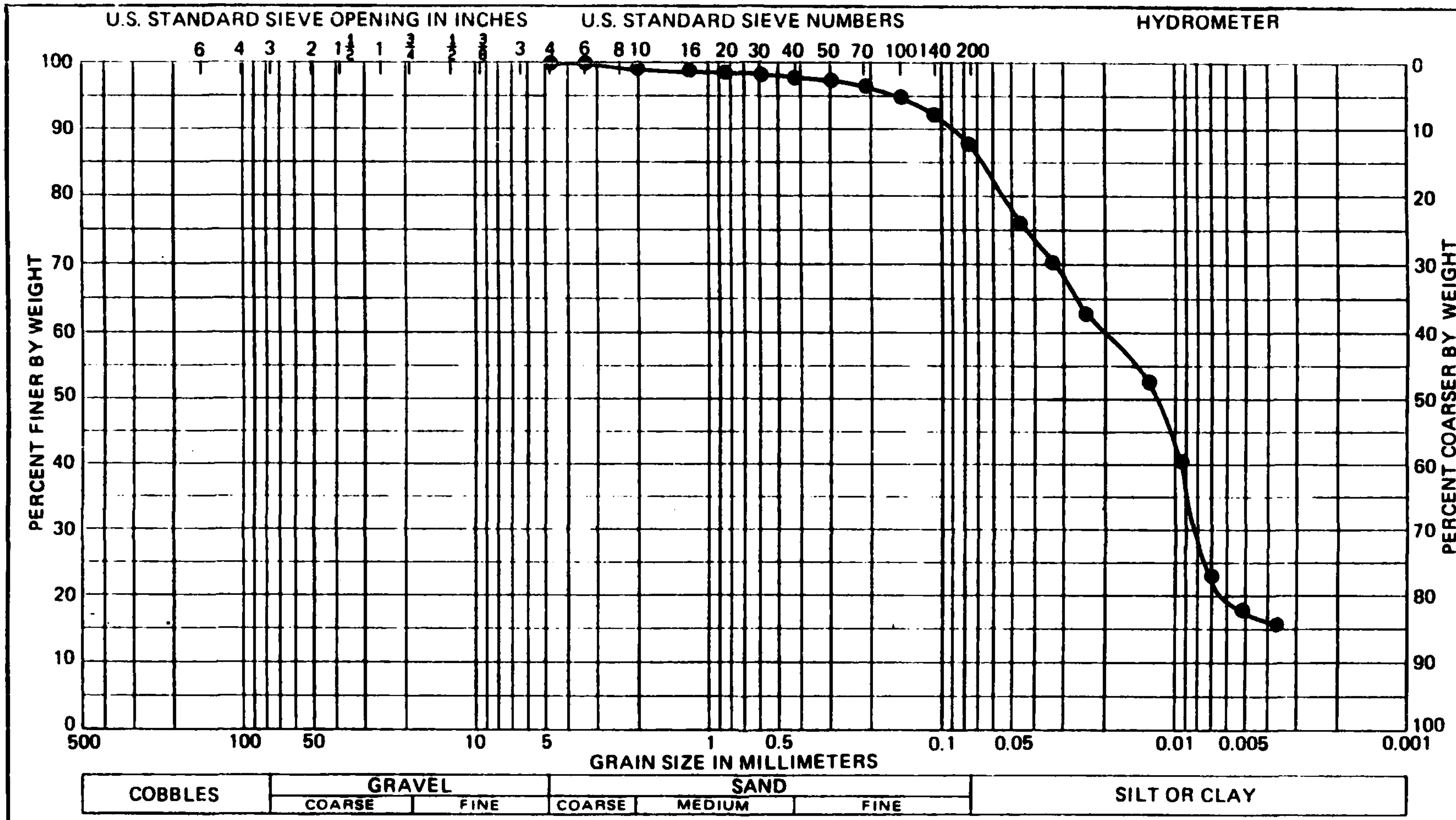
- a. The floating dike or excavation and placement form of dike construction should be used along the southwest corner near the state wetland area.
- b. If the site is to contain contaminated dredged material, 2 ft of dike freeboard should be maintained above the design storm surge.
- c. It is not recommended to use Area C, shown in Figure D1, as a disposal area because of the high costs of relocating the existing structures.
- d. The outboard toe of any dike at the mudline should be setback from the edge of the closest piling or ship channel at least 200 ft.

APPENDIX E: FOUNDATION SOIL PROPERTIES

The void ratio-effective stress and void ratio-permeability data for the assumed compressible foundation soil are shown below. A value of 2.70 was used for the specific gravity of this material.

Void Ratio, e	Effective Stress lb/ft^2	Permeability ft/day
4.00	0.0	5.472E-03
3.90	0.5	5.040E-03
3.85	1.1	4.824E-03
3.80	1.9	4.680E-03
3.70	4.0	4.320E-03
3.60	8.2	3.960E-03
3.50	13.2	3.672E-03
3.40	19.8	3.341E-03
3.30	28.0	3.053E-03
3.20	37.4	2.808E-03
3.10	50.0	2.563E-03
3.00	64.0	2.333E-03
2.90	84.0	2.131E-03
2.80	110.0	1.915E-03
2.70	140.0	1.728E-03
2.60	182.0	1.541E-03
2.50	240.0	1.382E-03
2.40	316.0	1.210E-03
2.30	400.0	1.051E-03
2.20	460.0	9.072E-04
2.10	700.0	7.776E-04
2.00	880.0	6.624E-04
1.90	1,140.0	5.400E-04
1.80	1,480.0	4.421E-04
1.70	1,900.0	3.528E-04
1.60	2,460.0	2.837E-04
1.50	3,200.0	2.232E-04
1.40	4,160.0	1.728E-04
1.30	5,400.0	1.339E-04
1.20	7,000.0	1.022E-04
1.10	9,000.0	7.632E-05
1.00	11,400.0	5.904E-05

APPENDIX F: SEDIMENT PROPERTIES



LL	PL	PI	GS	NAT W, %	ORG. CONT.
78	35	43	2.59		7.9 %

CLASSIFICATION

SANDY CLAY (CH), GRAY

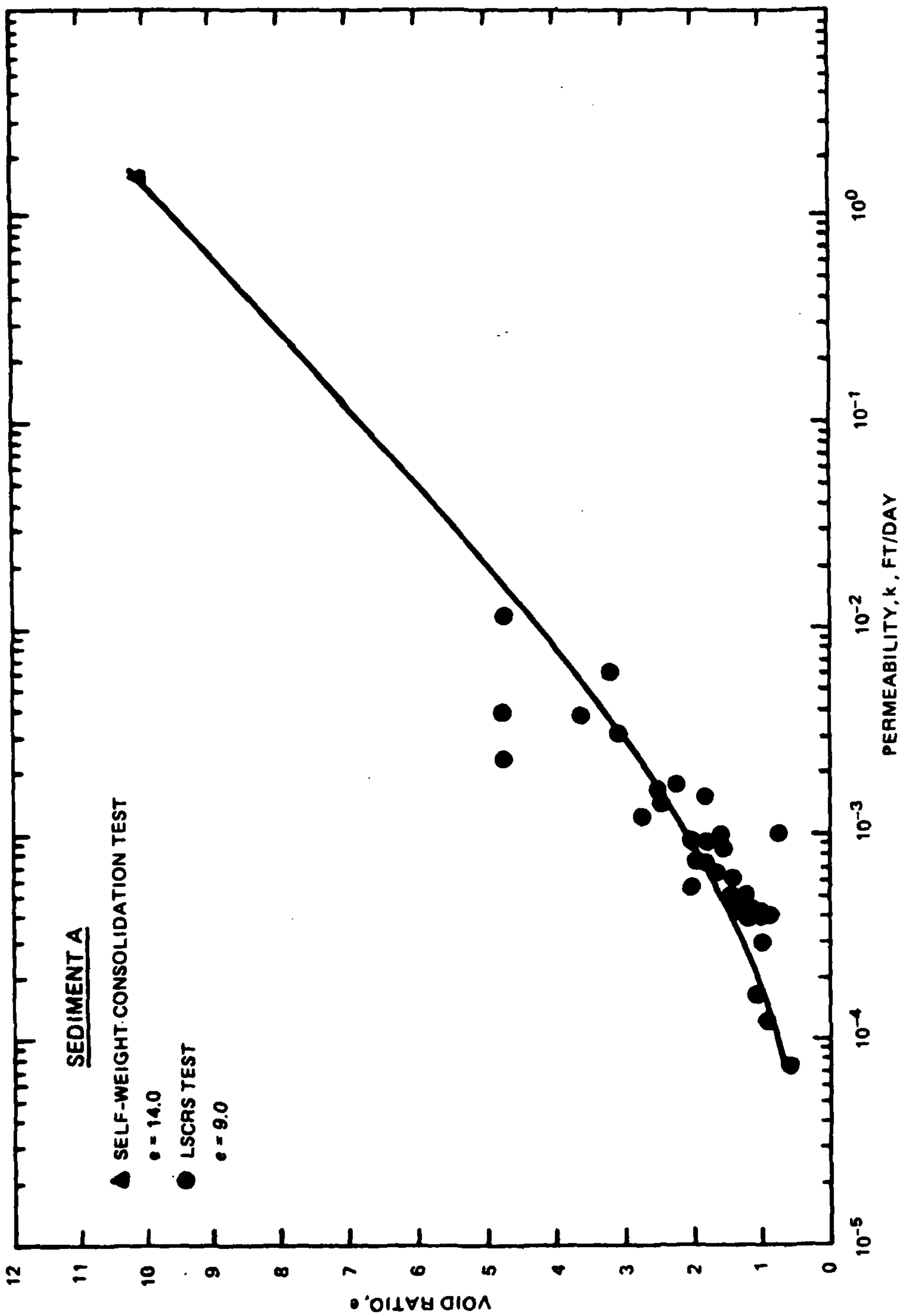
GRADATION CURVE

PROJECT NEW YORK DISTRICT

SEDIMENT A

BORING NO. 0 SAMPLE NO. 17

DEPTH/ELEV 0 DATE 26 JUL 84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LSCRS TEST
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PERMEABILITY, k, FT/DAY
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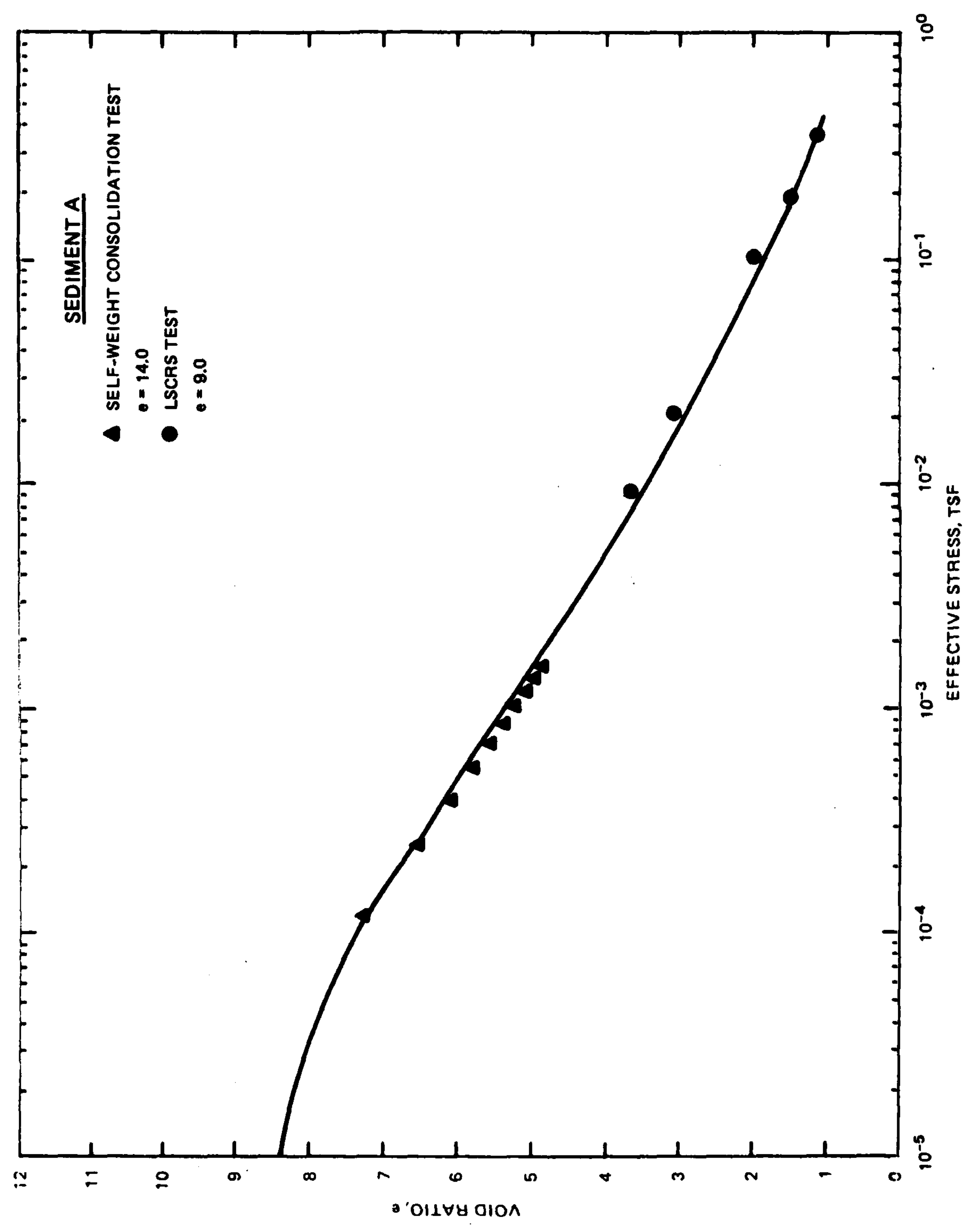
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SELF-WEIGHT CONSOLIDATION TEST
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LSCRS TEST
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EFFECTIVE STRESS, TSF
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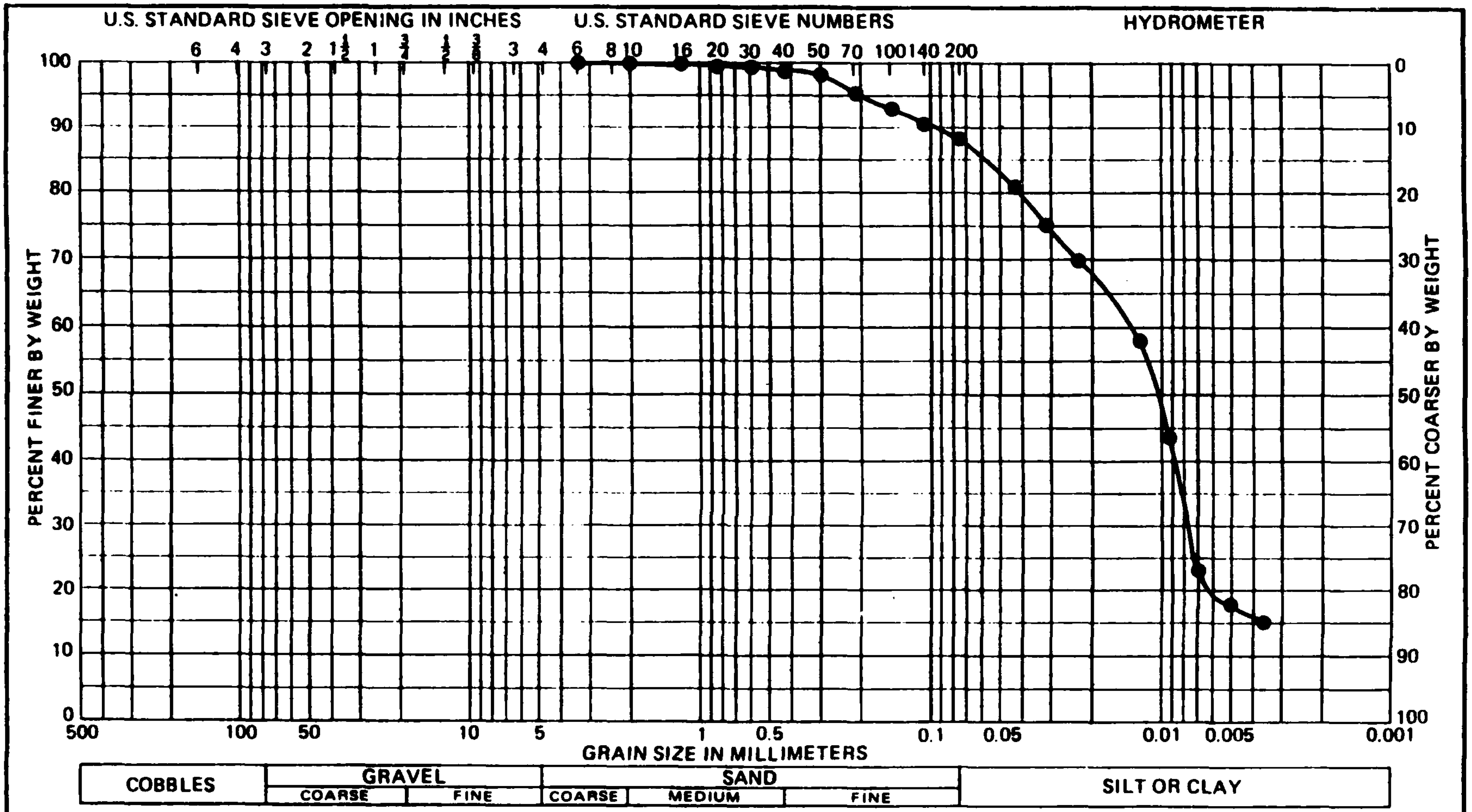


LL	PL	PI	GS	NAT W, %	ORG.CONT.
84	35	49	2.57		8.5%

CLASSIFICATION

CLAY (CH), GRAY; WITH SAND

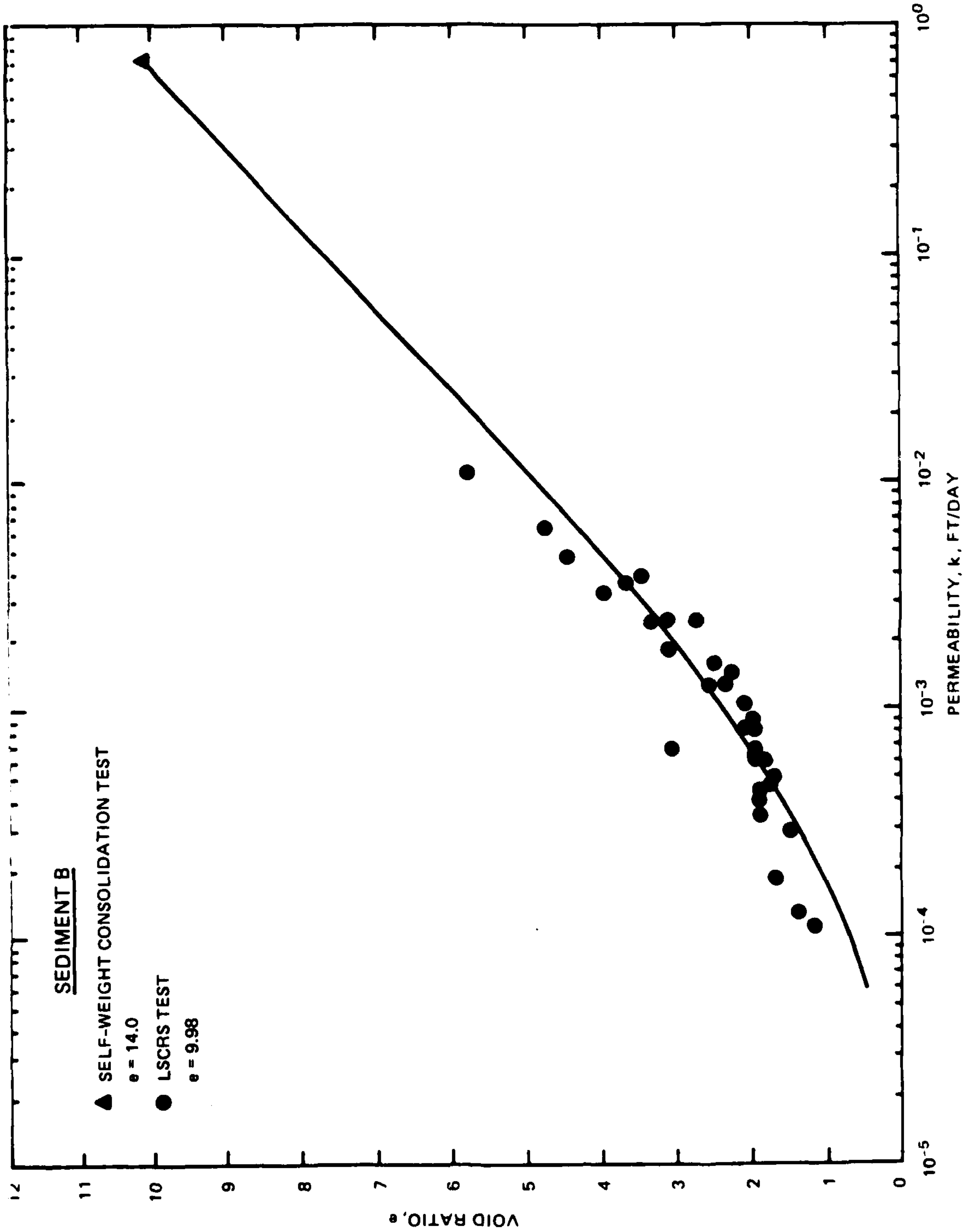
GRADATION CURVE

PROJECT NEW YORK DISTRICT

SEDIMENT B

BORING NO. 0 SAMPLE NO. 4

DEPTH/ELEV 0 DATE 31 JUL 84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LSCRS TEST
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PERMEABILITY, k, FT/DAY
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2
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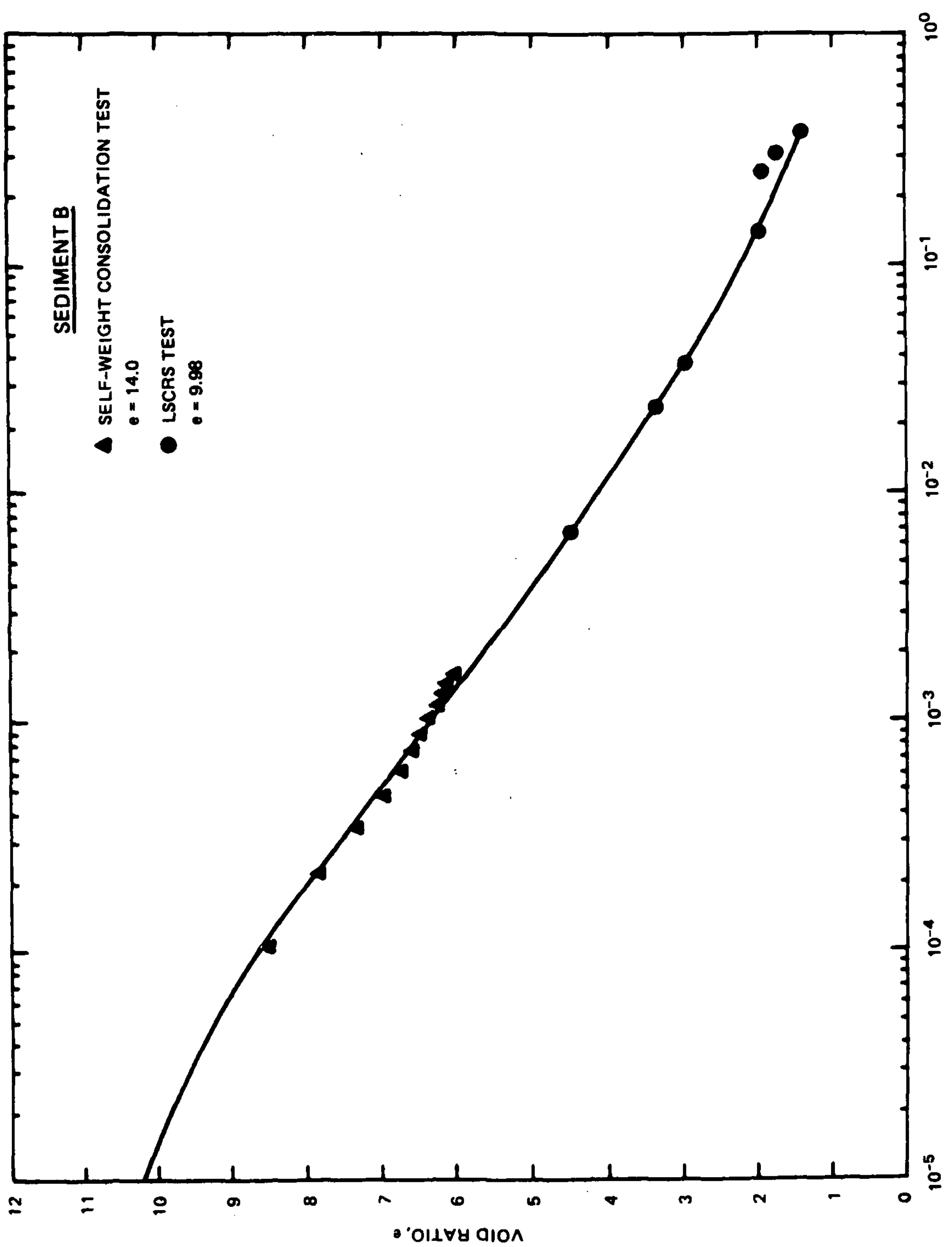

SEDIMENT B
SELF-WEIGHT CONSOLIDATION TEST
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LSCRS TEST
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VOID RATIO, e
EFFECTIVE STRESS, TSF
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10
9
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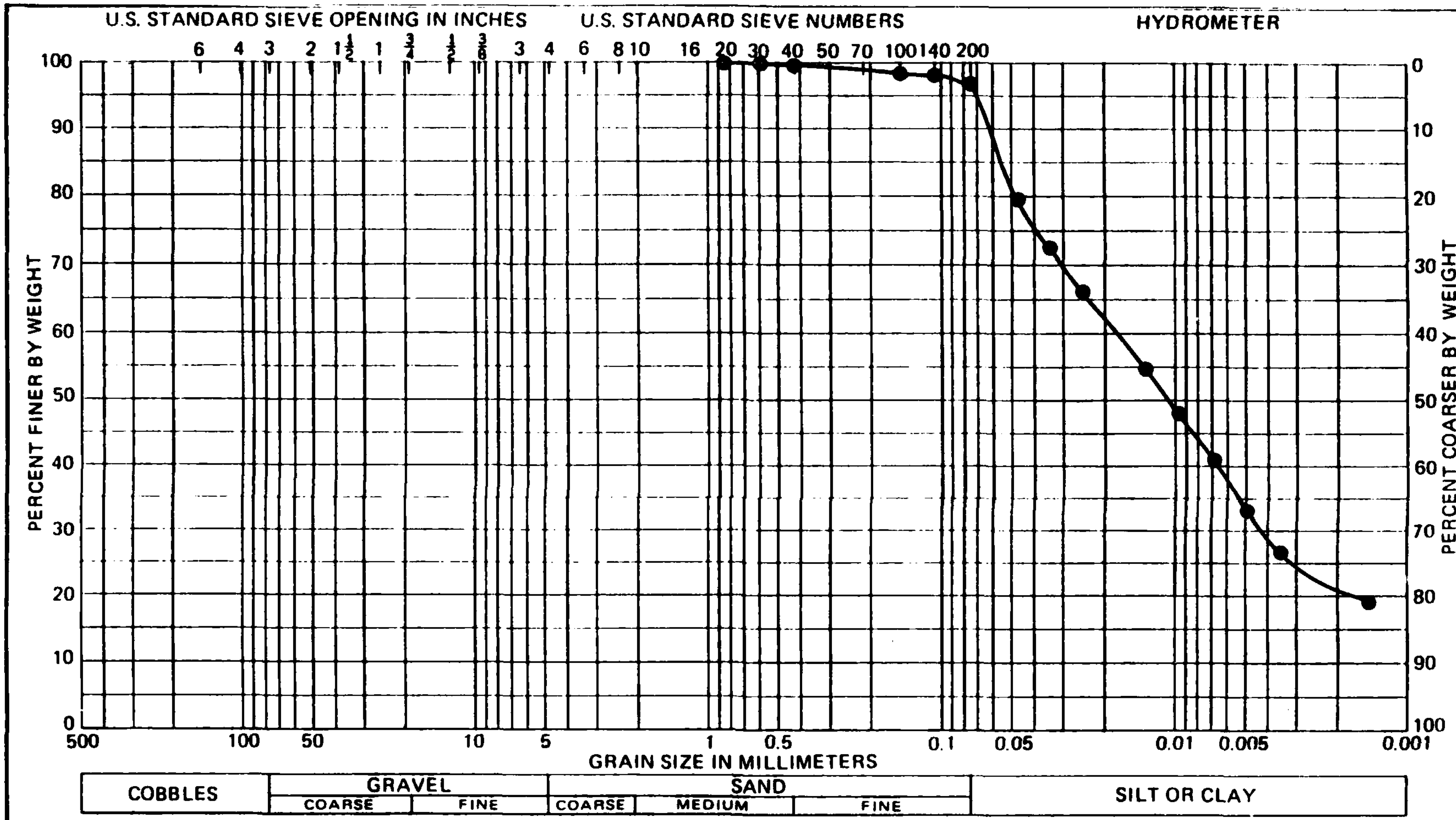


LL	PL	PI	GS	NAT W, %	ORG. CONT.
114	41	73	2.60		9.1%

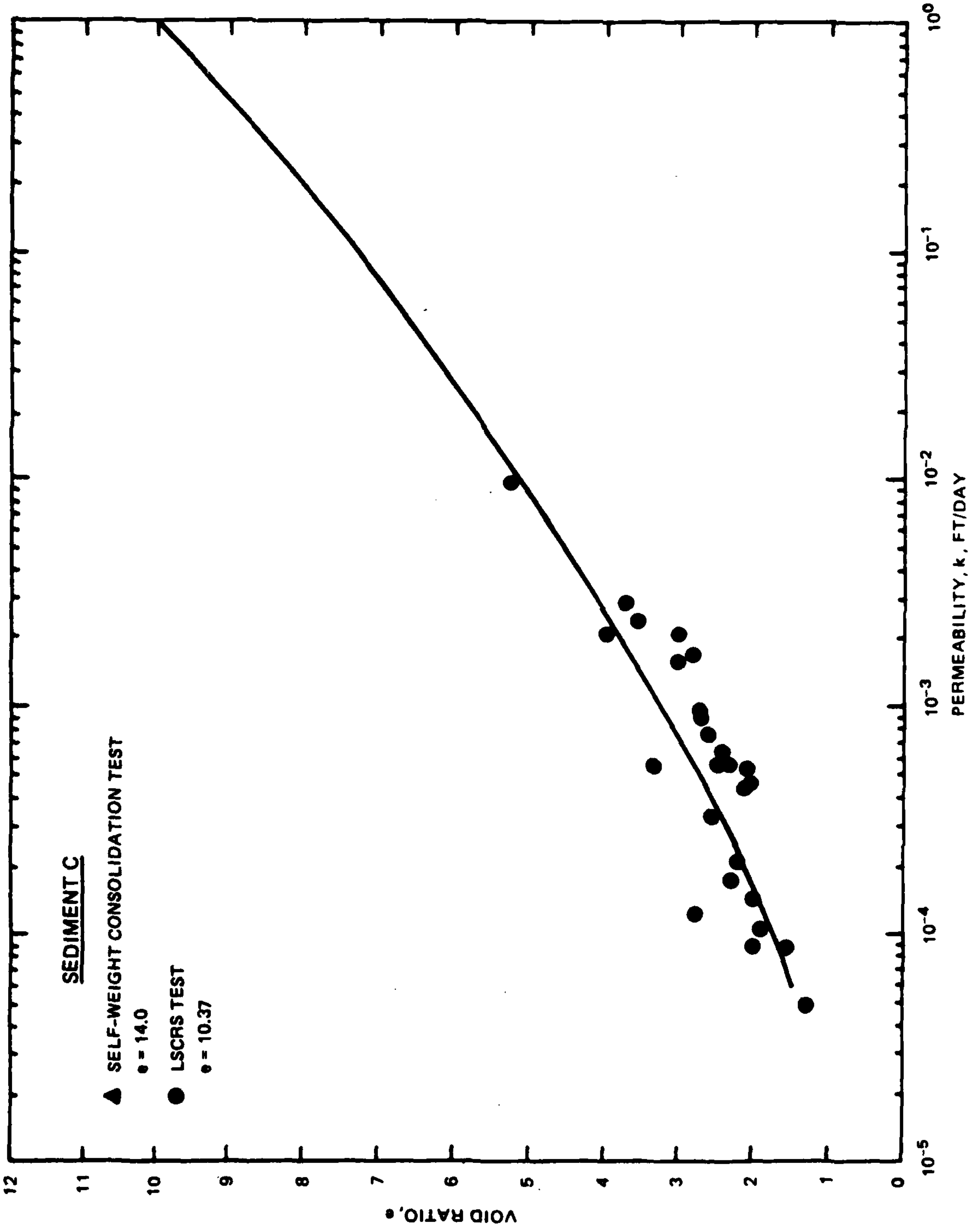
CLASSIFICATION

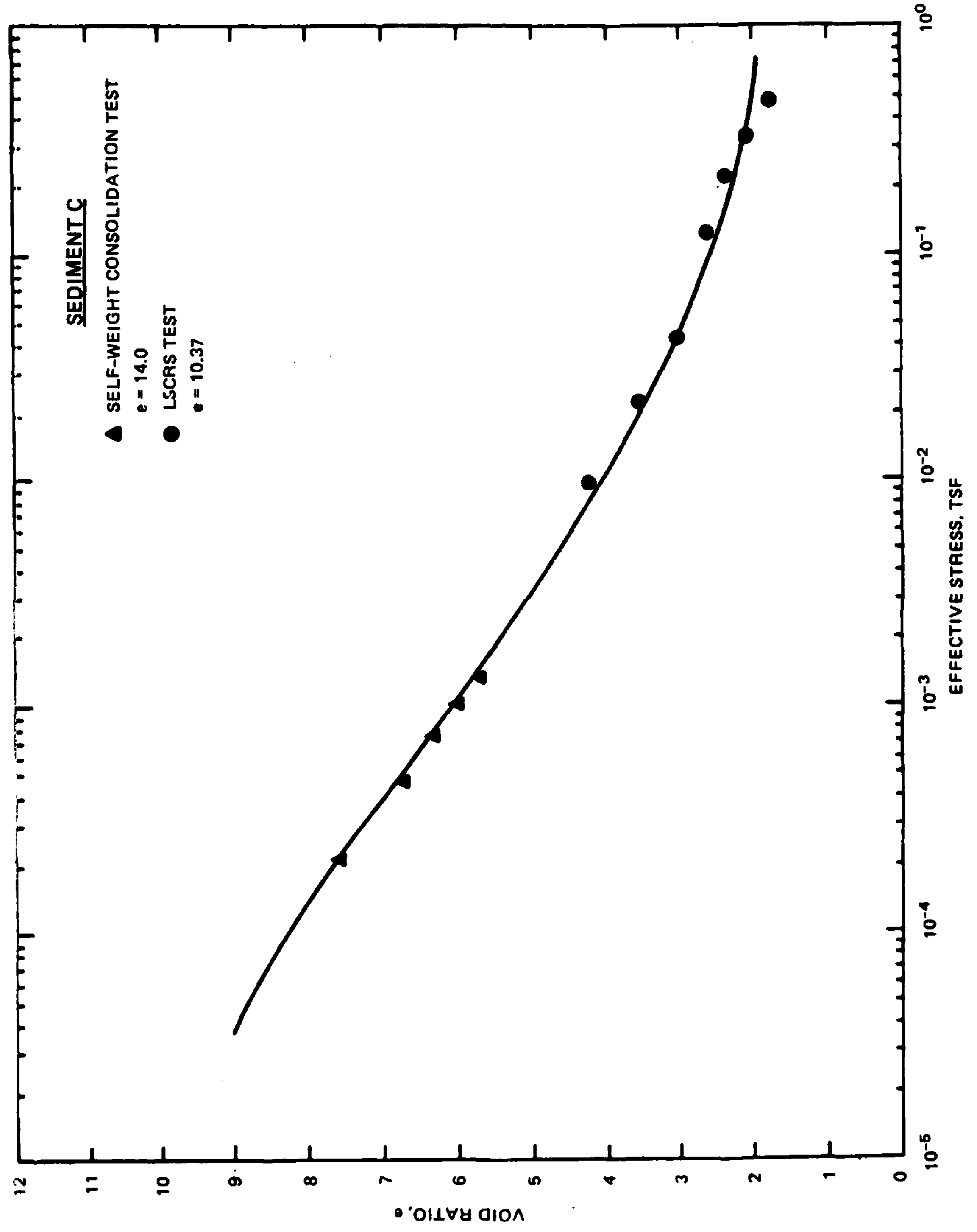
CLAY (CH), GRAY TRACE OF SAND

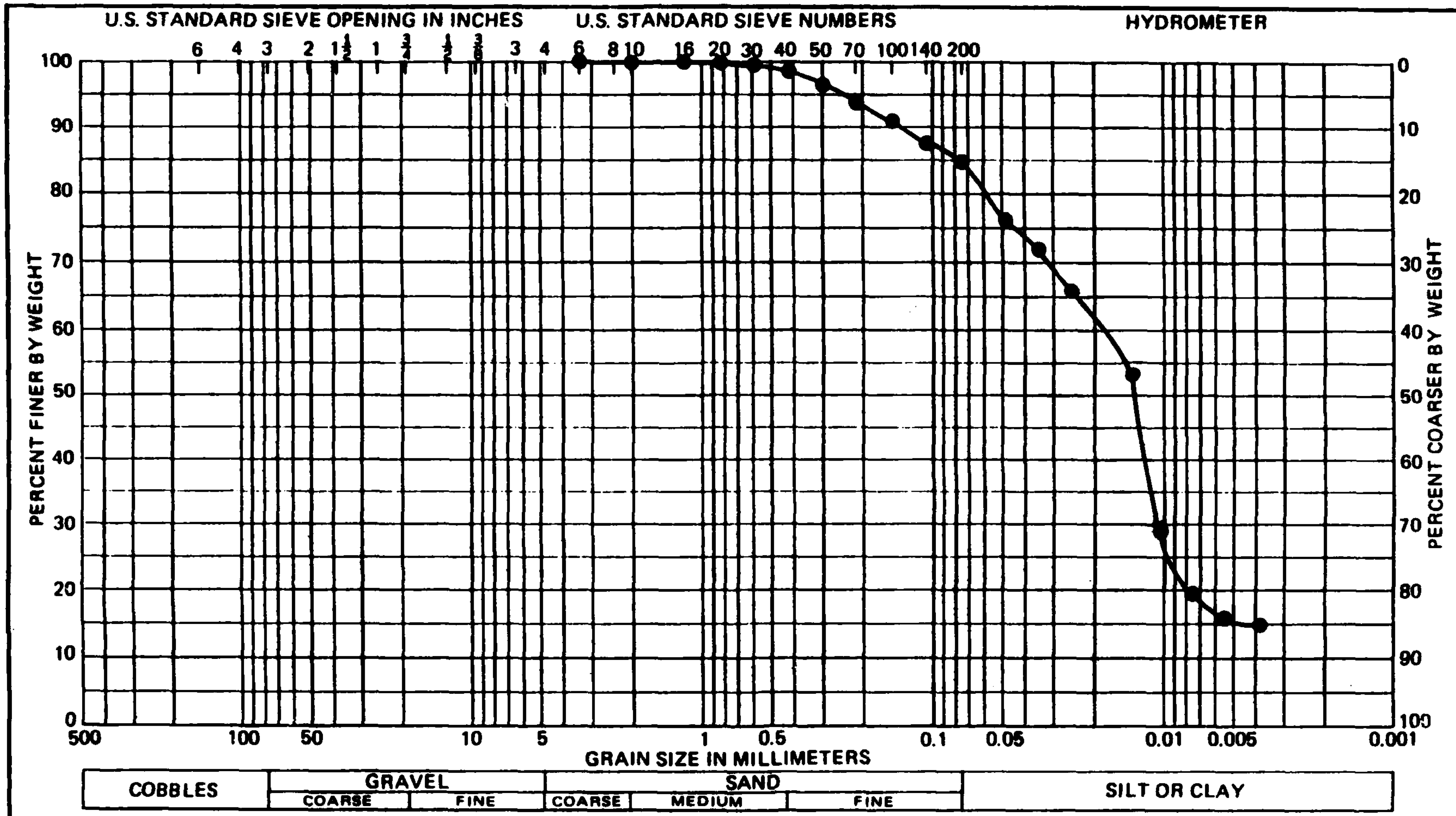
GRADATION CURVE

PROJECT NEW YORK DISTRICT
SEDIMENT C

BORING NO. 0 SAMPLE NO. 12
DEPTH/ELEV 0 DATE 26 JUL 84


SEDIMENT C
SELF-WEIGHT CONSOLIDATION TEST
e = 14.0
LSCRS TEST
e = 10.37
VOID RATIO, e
0
1
2
3
4
5
6
7
8
9
10
11
12
PERMEABILITY, k, FT/DAY
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}


SEDIMENT C
SELF-WEIGHT CONSOLIDATION TEST
e = 14.0
LSCRS TEST
e = 10.37
VOID RATIO, e
0
1
2
3
4
5
6
7
8
9
10
11
12
EFFECTIVE STRESS, TSF
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}



LL	PL	PI	GS	NAT W, %	ORG. CONT
90	40	50	2.42		12.3%

CLASSIFICATION

SANDY CLAY (OH), GRAY

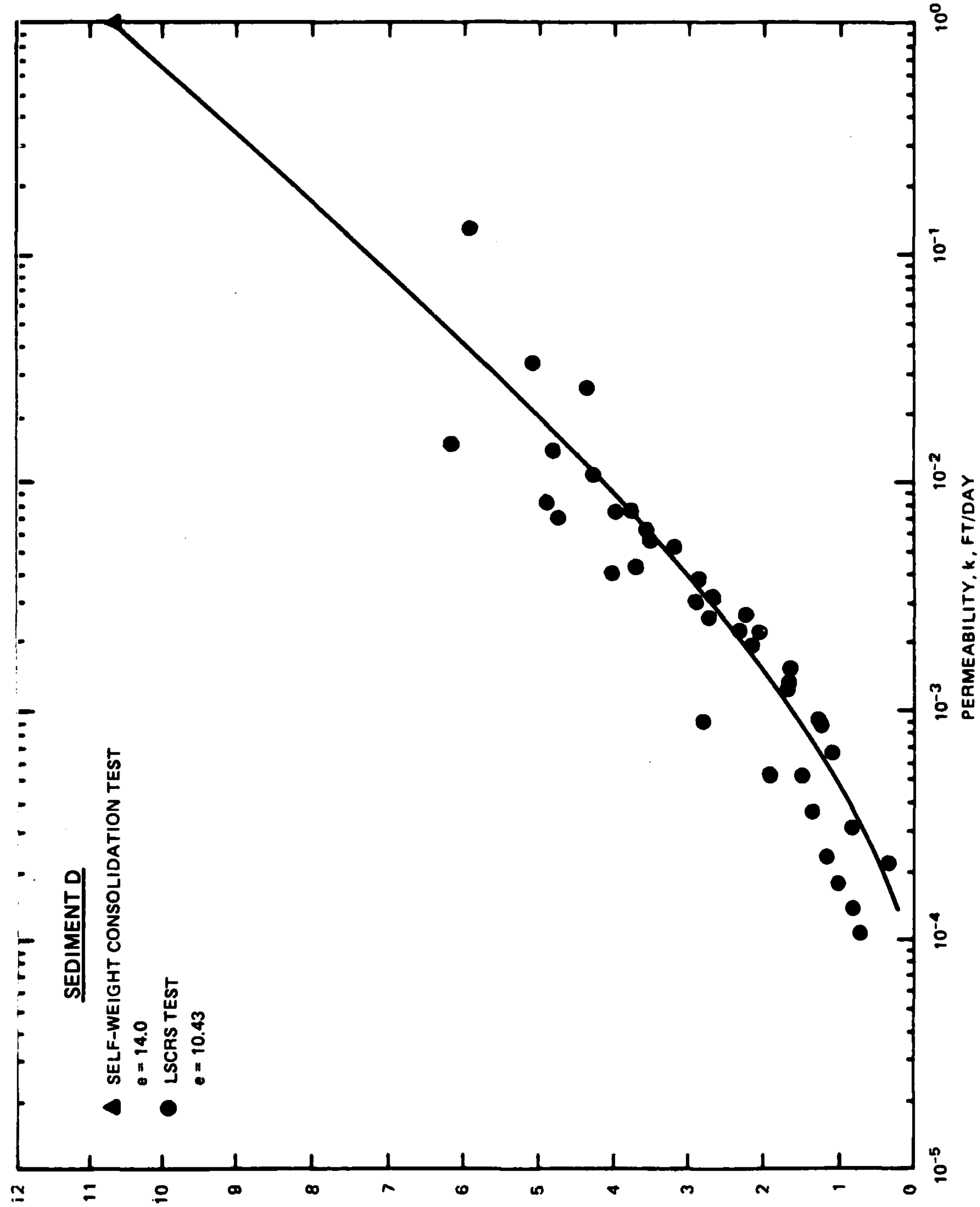
GRADATION CURVE

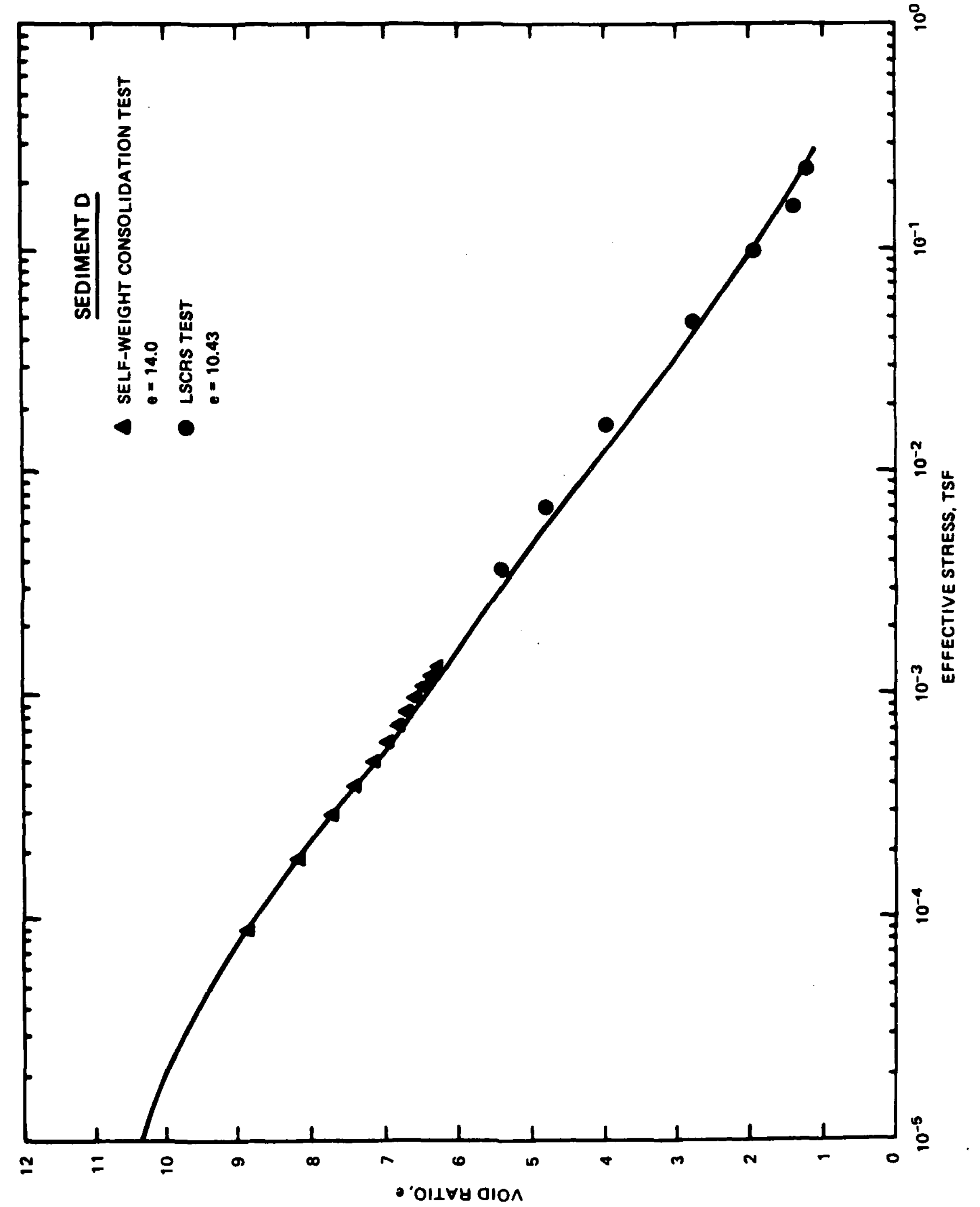
PROJECT NEW YORK DISTRICT

SEDIMENT D

BORING NO. 0 SAMPLE NO. 20

DEPTH/ELEV 0 DATE 31 JUL 84


SEDIMENT D
SELF-WEIGHT CONSOLIDATION TEST
e = 14.0
LSCRS TEST
e = 10.43
VOID RATIO, e
PERMEABILITY, k, FT/DAY
0
1
2
3
4
5
6
7
8
9
10
11
12
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}


SEDIMENT D
SELF-WEIGHT CONSOLIDATION TEST
e = 14.0
LSCRS TEST
e = 10.43
VOID RATIO, e
EFFECTIVE STRESS, TSF
0 1 2 3 4 5 6 7 8 9 10 11 12
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0}